

THE EFFECT OF LARGE EXTERNAL STORES
ON THE LOW-SPEED PITCHING AND YAWING CHARACTERISTICS
OF A 60° DELTA WING

*within front
3
12T*


A THESIS
Presented to
the Faculty of the Graduate Division
Georgia Institute of Technology

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Aeronautical Engineering

By
Jesse Musco Boulware

June 1955

In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institution shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or, in his absence, by the Dean of the Graduate Division when such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.



THE EFFECT OF LARGE EXTERNAL STORES
ON THE LOW-SPEED PITCHING AND YAWING CHARACTERISTICS
OF A 60° DELTA WING

Approved:

[Handwritten signature]

Date Approved by Chairman:

April 15, 1955

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Professor John J. Harper for the suggestion of the topic and for his valuable aid, criticisms, and guidance throughout the development of this thesis. Gratitude is also extended to Doctor Arnold L. Ducoffe and Doctor Mario J. Goglia for their review and constructive criticisms of the topic.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
LIST OF TABLES	iv
LIST OF FIGURES	v
LIST OF SYMBOLS	vii
SUMMARY	ix

Chapter

I. INTRODUCTION	1
II. APPARATUS AND MODELS	3
III. PROCEDURE	7
IV. DISCUSSION OF RESULTS	11
V. CONCLUSIONS	20
VI. RECOMMENDATIONS	21
APPENDIX	22
BIBLIOGRAPHY	50

LIST OF TABLES

Table	Page
1. Numerical Values of Lateral Derivatives, $\Psi = 4^\circ$	23

LIST OF FIGURES

Figure	Page
1. Assembled Delta-Wing Model	24
2. Dimensions of Delta	25
3. Fuselage Dimensions	26
4. External Store	27
5. Photograph of External Stores	28
6. View of Complete Model Mounted in Tunnel	29
7. Variation of Longitudinal Derivatives in Yaw, $\alpha = 0^\circ$	30
8. Lift Coefficient Variation in Yaw, $\alpha = 12^\circ$	31
9. Drag Coefficient Variation in Yaw, $\alpha = 12^\circ$	32
10. Pitching Moment Coefficient Variation in Yaw, $\alpha = 12^\circ$	33
11. Lateral Derivatives in Yaw, $L/D = 12$, $\alpha = 0^\circ$	34
12. Lateral Derivatives in Yaw, $L/D = 10$, $\alpha = 0^\circ$	35
13. Lateral Derivatives in Yaw, $L/D = 8$, $\alpha = 0^\circ$	36
14. Lateral Derivatives in Yaw, $L/D = 12$, $\alpha = 12^\circ$	37
15. Lateral Derivatives in Yaw, $L/D = 10$, $\alpha = 12^\circ$	38
16. Lateral Derivatives in Yaw, $L/D = 8$, $\alpha = 12^\circ$	39
17. Lateral Derivatives in Yaw, 22% position, $\alpha = 0^\circ$	40
18. Lateral Derivatives in Yaw, 40% position, $\alpha = 0^\circ$	41
19. Lateral Derivatives in Yaw, 60% position, $\alpha = 0^\circ$	42
20. Lateral Derivatives in Yaw, 22% position, $\alpha = 12^\circ$	43
21. Lateral Derivatives in Yaw, 40% position, $\alpha = 12^\circ$	44

LIST OF FIGURES (CONTINUED)

Figure	Page
22. Lateral Derivatives in Yaw, 60% position, $\alpha = 12^\circ$	45
23. Variation of Lateral Derivatives with position, $\alpha = 0^\circ$. .	46
24. Variation of Lateral Derivatives with position, $\alpha = 12^\circ$. .	47
25. Variation of Lateral Derivatives with Fineness Ratio, $\alpha = 0^\circ$	48
26. Variation of Lateral Derivatives with Fineness Ratio, $\alpha = 12^\circ$	49

LIST OF SYMBOLS

C_D	drag coefficient, (drag/qs)
C_L	lift coefficient, (lift/qs)
C_M	pitching-moment coefficient, (pitching moment/qs \bar{c})
C_l, C_ℓ	rolling-moment coefficient, (rolling moment/qs b)
C_n	yawing-moment coefficient (yawing moment/qs b)
C_Y	side-force coefficient, (side force/qs)
b	wing span, feet
c	local wing chord, feet
\bar{c}	mean aerodynamic chord, feet
D	store diameter, inches
L	store length, inches
L/D	store fineness ratio (length/diameter)
MAC	mean aerodynamic chord, inches, feet
R_e	effective Reynolds number
S	wing area, square feet
q	dynamic pressure, ($\rho V^2/2$)
u	subscript, refers to wind axes
y	wing semi-span station, feet
V	free-stream velocity, feet per second
C_{l_Ψ}	rolling moment derivative dC_l/d_Ψ
C_{n_Ψ}	yawing moment derivative, dC_n/d_Ψ
α	model angle of attack, degrees
ρ	mass density of air, slugs per cubic foot

LIST OF SYMBOLS (CONTINUED)

Ψ model angle of yaw, degrees

Γ_{eff} effective dihedral angle, degrees

SUMMARY

This paper is the result of an experimental low speed investigation made in the Georgia Tech nine-foot-diameter wind tunnel to determine the effect of large external stores on the yawing characteristics of a 60° delta-wing fuselage combination. Two stores with fineness ratios of 8, 10, and 12, symmetrically located at 22, 40, and 60 per cent semi-span stations on the lower surface of the wing of the yawing model were studied. The wing airfoil was an NACA 0009 section, swept 60° at the quarter-chord line. The stores had a diameter equivalent to approximately 24 inches, full scale, and were pylon mounted at the leading edge of the wing. Runs were made at constant angles of attack of zero and twelve degrees while the model was being yawed to a maximum of twenty degrees.

The results indicate that while all the coefficients are effected, the most critical is the yawing moment coefficient. The yawing moment coefficient and the yawing moment derivative were found to be very sensitive to store location. The increment due to the stores changed from a destabilizing force to a stabilizing one as the stores were moved spanwise along the swept leading edge of the wing. Consideration should be given to the low speed condition before determining the placement of similar large stores.

The resultant values of the lateral derivatives, C_{n_Y} and C_{l_Y} indicate that consideration should also be given to the store effect on the low speed dynamic stability of the airplane when loaded with missiles of this size and type.

CHAPTER I

INTRODUCTION

The trend in modern air warfare which has led to the development of high speed, intercontinental bombardment aircraft, plus the development of thermo-neuclear weapons, presents a serious threat to those whose task is the defense of the continental United States and Canada, and has required changes in certain defensive tactics. The successful development of neuclear explosives now enables one aircraft carrying one bomb to completely destroy or neutralize large cities. The defensive measures which were effective against the bombers of World War II are hopelessly inadequate against the sonic and near sonic long range, high altitude aircraft now in existence or under development. The flight time from the point of first contact with the defensive radar screen to the target is very brief for an aircraft capable of sonic speeds. This speed not only makes interception difficult, but it also effectively limits the intercepting aircraft to one attack before it loses contact with the invading craft.

Obviously, since one aircraft armed with thermo-neuclear weapons can accomplish the destruction of its target city, none must be allowed to penetrate the defensive screen. One trend toward the achievement of this necessary defense measure has led to the development of very large air to air rockets of sufficient size to insure the destruction of the attacker if interception is made. These rockets, ranging in size up to several feet in diameter, can not usually be stored internally by inter-

ceptor-type aircraft, consequently, they must be carried as external stores affixed to the wing or fuselage as dictated by aerodynamic and structural considerations. It is logical to assume that the presence of these large bodies will result in changes of the aerodynamic characteristics of the aircraft, especially in yawed flight.

It is the purpose of this paper, within a limited scope, to set forth the results of a series of wind tunnel tests designed to show the effects of such stores on a 60° delta wing with fuselage at low speeds. The delta wing was selected as being a planform, which while in current use on high speed aircraft, has not been as extensively investigated as have the more common types.

The parameters which were varied in the course of the investigation were the span-wise location, and fineness ratio of the two stores, which were mounted symmetrically on the lower surface of the wing, and the angle of yaw of the entire model. All runs were made at constant angles of attack of zero and twelve degrees.

It is not intended that the data so obtained will dictate the placement of the stores, but rather that it will show the effects at low speeds, once the position of the stores has been determined by high speed considerations. It is felt that this information will be of value in predicting the take-off and landing characteristics of delta winged aircraft so loaded. It is possible, however, that low speed flight might be seriously enough affected that a compromise between high and low speed optimum will be required.

The results include the effect of the large external stores on the force and moment coefficients.

CHAPTER II

APPARATUS AND MODELS

The tests described and discussed in this report were conducted in the Georgia Tech nine-foot-diameter wind tunnel. This tunnel is of the single return type, with a closed circular test section vented to the atmosphere. Power is provided by a 200 horsepower synchronous motor which drives a 15 foot-diameter, four-bladed, variable pitch propeller. The wind velocity in the test section is controlled by adjustment of the propeller pitch. Velocities up to 150 miles per hour are obtainable using the closed circular jet. The model was mounted on a conventional three support system, having two main struts forward and one strut aft. The unit was yawed by revolving the balance turntable and attitude was controlled by remotely raising or lowering the rear strut. The forces and moments on the model were measured by a remotely operated, six component-type balance system. It is an electro-mechanical, completely automatic beam balance having an electronic control system and a mechanical servo balance drive.

The model used consisted of a delta wing-fuselage combination plus two variable length, finned missiles simulating the large stores. This model was designed to be mounted on the three strut balance described above. All three mounting points were in the wing itself.

The wing had a delta planform with 60° sweep of the quarter-chord line. The wing span was 48 inches, resulting in an aspect ratio of 1.73. The airfoil used was an NACA 0009 with sections parallel to the plane of

symmetry. The wing was constructed of laminated mahogany, with the exception of the tips which were shaped from solid aluminum. The holes for the forward balance strut mountings were located at the intersection of the quarter-chord lines and the mean aerodynamic chord lines of each panel. The rear strut was attached at the wing centerline. Detailed dimensions are shown in Fig. 2 in the appendix of this report.

The fuselage was a body of revolution utilizing the ordinates of an NACA 64012 airfoil with an eighty inch chord. The body was cut at the point of maximum diameter (40 per cent chord) and a straight cylindrical section of this maximum diameter and twenty inches in length inserted therein. The last 27.5 per cent of the basic shape was cut off to give a blunt base five inches in diameter. The basic airfoil was modified by substituting a straight taper from approximately the sixty per cent chord point aft to the trailing edge to eliminate the normal cusp of the 64 series airfoils. The fuselage was lathe turned from mahogany blocks in three sections; nose, center, and tail, and then joined by glue and dowels after turning. It was then parted along the horizontal plane of symmetry and contoured to receive the delta wing in a symmetric mid-wing position. The two halves were fastened together by two steel bolts, one running vertically through the nose and one running vertically through the tail. The upper fuselage half was fitted with a quarter inch dowel which was received by a hole in the wing on the centerline, thus fixing the alignment of the wing and fuselage. The lower half of the fuselage was slotted to allow passage of the tail mounting strut. Dimensional details are given in Fig. 3.

The stores were constructed of mahogany and aluminum. The forward

section had a nose of mahogany which was a 37.5 inch radius ogive, 3.5 store diameters in length. The center sections were formed by lengths of three-inch outside-diameter aluminum tubing. Three sets of tubing were fabricated in lengths which would allow three different overall store lengths, representing length to diameter, or fineness ratios of 8, 10, and 12. The tail section was turned from solid mahogany to an outside diameter of three inches and slotted to admit the 1/8 inch aluminum tail fins. The fin leading edges were rounded to a radius of 1/16 of an inch. The three major portions were joined by a long quarter inch tie-rod which extended through the tail block and the center tubing and threaded into an aluminum insert in the aft end of the nose section. See Figs. 4 and 5 for more complete details.

The mounting pylons were constructed of laminated walnut. The airfoil section used was an NACA 0009. The pylon span was 4.5 inches (1.5 store diameters) and its chord was a constant 7.6 inches. It was mortised into the forward section of the store and secured in place by two quarter inch bolts which extended through the store and pylon and threaded into a steel cap on the end of the pylon opposite to the store. This cap, when the stores were mounted on the wing, rested on two spacer bushings which were of such a length as to maintain a minimum of 1.5 store diameters between the store body and the wing surface in all span-wise positions. An individual set of bushings was required for each separate station along the wing. Each pylon-store assembly was attached to the wing by two steel bolts which extended through the wing and spacer bushings and into tapped holes in the steel cap of the pylon. The space between the steel cap and the curved wing surface was filled in all

positions with plaster of paris. Pylon details can be seen in Figs. 4 and 5.

The stores were positioned chordwise on the wing, so that the leading edge of the pylon was coincident with and perpendicular to the wing leading edge. The leading edge or nose of the missile was 10.5 inches, or 3.5 diameters, ahead of the wing leading edge, measured along a line parallel to the store centerline.

A photograph showing the model mounted in the tunnel with stores of $L/D = 10$ at the 22 per cent span station is included as Fig. 6 in the appendix.

In order that realistic dimensions might be maintained on the tunnel model, a scale of eight to one between a representative full scale interceptor type aircraft and the model was selected. This scale was used in all cases where it was felt that certain maximum or minimum dimensions could not be entirely arbitrary with respect to full scale aircraft.

CHAPTER III

PROCEDURE

The basic tests involved in the course of this investigation consisted of yaw runs at two constant angles of attack for each model configuration, plus one pitch run. This single run varying the angle of attack at zero yaw angle was made with the wing-fuselage combination alone. Its purpose was to determine the zero lift angle for the model without stores. Having once found this angle, the model was set at the zero lift position and the tunnel-control-station dial which read angle of attack was set to zero. Since the model was symmetrical, it was assumed that this was also the geometric zero with respect to the tunnel airflow. The dial was not zeroed again, consequently, all subsequent tests were made at the same geometric angle of attack as was used for the clean configuration.

In all, thirteen different configurations were tested. These consisted of the wing-fuselage combination without stores and with stores mounted at 22, 40, and 60 per cent semi-span stations, each store fineness ratio being tested at each spanwise position. In addition, the wing-fuselage combination was also run with only the store mounting pylons at each station. For this group of tests, two new pylons were fabricated, identical to the original set described on page 5, with one exception, the tenon was omitted from the exposed end, since the stores were not attached.

The wind-on runs were made at two constant angles of attack, zero

and twelve degrees, the angle of yaw of the model being varied from zero to twenty degrees in two degree increments at both pitch settings. All six forces and moments were measured and recorded at each two degree interval. During all runs, the wind velocity at the model was held to a constant 119.6 miles per hour indicated airspeed, corresponding to a dynamic pressure, q , of 36.63 pounds per square foot and an effective Reynolds number, R_e , of approximately 3.9 million. The tunnel turbulence factor is 1.34.

The tunnel corrections for wall, alignment and support influences presented a more difficult problem. Wall and alignment corrections can not be satisfactorily evaluated for tests involving a yawed model, since the resulting flow in the jet is no longer symmetric. Consequently, it was decided, as a compromise, to use the wall and alignment corrections which had been used on this same wing in previous test programs which involved only changes in angle of attack. The available data for these two effects was plotted against the lift coefficient. These corrections themselves are questionable for use when the model is yawed, and the variation in lift coefficient with increasing yaw angle is relatively small. Therefore, values for the wall and alignment corrections at a lift coefficient corresponding to that of the clean model at zero and twelve degrees angle of attack were selected and used as constant corrections for all yaw angles, and all store conditions. The tare and interference effects of the mounting struts and windshields on the drag coefficient also presented a problem, since the Georgia Tech wind tunnel does not have the yawing image support system necessary to properly obtain this corrective data. These tare and interference values were re-

quired for a subsequent pitch study which used the same models and equipment used in this program. Consequently, during this program, a tare and interference survey was made in pitch, using the non-yawing image system, and the resulting drag corrections were applied, again as a compromise. They are not exact once the model has been yawed, but the undetermined variation was assumed to be small, hence constant values were selected for use in the same manner as for the wall and alignment corrections.

In all tests the model was run inverted since the balance supports would have caused serious and indeterminable interference in the flow pattern had the stores been mounted below the wing. Certain procedure changes were necessary before the data could be reduced. When the model is inverted an angle of attack or yaw which is positive with respect to the model axes is negative with respect to the tunnel balance axes. With respect to the balance system, the model was operated at negative angles of attack and positive angles of yaw, that is, nose down and to the right. However, a number of acceptable and convenient sign changes were made and as a result the coefficient curves appearing in the appendix of this report represent the model in a conventional positive attitude, that is to say that both the angles of attack and the angles of yaw are positive. This is the condition which would result if the model had been operated right side up with its nose up and to the right.

The only model changes required between each run were the shifting of the stores from one span station to another and the substitution of different store center sections to vary the stores' fineness ratio at each span station.

The data obtained from these wind tunnel tests were corrected for the balance gravity tares and dial zero readings and converted into standard coefficient form. The tunnel corrections discussed above were then applied to the uncorrected coefficients where necessary. The resulting coefficients, which are with respect to the wind axes, are presented in curve form in the appendix of this report as Figs. 7 through 22, and are discussed and analyzed in the following chapter.

CHAPTER IV

DISCUSSION OF RESULTS

The results of this investigation are presented in Figs. 7 through 24 as non-dimensional coefficients plotted versus angle of yaw and as lateral derivatives plotted versus store fineness ratio and spanwise position. In the following discussion the effects of store fineness ratio and spanwise location will be evaluated. Primary emphasis will be placed on the side force, yawing moment and on the rolling moment coefficient. The longitudinal coefficient curves are presented with only a minimum of discussion, especially for those curves representing model operation at a nominal zero angle of attack. As also in the case of the lateral coefficients, the zero angle of attack condition is considered the least important, since it is not usually associated with low speed flight.

Longitudinal coefficients, $\alpha = 0^\circ$. --The lift coefficient curves show a general shift in the negative direction for all store positions, except for $2y/b = 22$ per cent. This latter curve changes to a positive increment to the clean-model curve above $\Psi = 10^\circ$. Pitch data taken at $\Psi = 0^\circ$, revealed a change in the zero lift angle, this angle becoming slightly positive as compared to that of the wing-fuselage combination without stores. The change was less than 0.5 degrees for all store configurations, however. Examination of Fig. 7 will show that even the clean configuration curve becomes negative as the yaw angle increases. There is no apparent trend shown with respect to the effect of the stores, other than

the general negative shift and the negative camber effects already noted. The drag coefficient curves of Fig. 7 show a consistent increase in drag at all span stations and all yaw angles. The stores-on drag being approximately twice that of the clean wing-fuselage combination at all angles of yaw. The pitching moment coefficient, $C_{M_{tr}}$, becomes more negative, or more stable, for the two inboard store locations and just slightly less stable than the wing-fuselage alone when the stores are mounted at the 60 per cent semi-span station. The drag due to the stores is stabilizing and at this low angle of attack may be the predominate effect. Fig. 7 shows only curves for $L/D = 12$. These are considered representative, there being little effect due to changes of fineness ratio.

Lift coefficient, $\alpha = 12^\circ$. --The presence of the stores in all spanwise locations and all fineness ratios increases the lift over that of the model without stores. The greatest increase for each store length is obtained with the store at the outermost position, the longest store being the most effective and the shortest being the least effective at this station. The increase in lift decreases sharply as the stores are moved toward the wing centerline. Also the effect of fineness ratio decreases and reverses as the stores move in, although at these positions the differences between the various lengths is quite small. The pylons alone have very little effect in any position. The increase in lift is greatest at smaller yawing angles and is most probably due to the change in the boundary layer flow as a result of the end plating effect of the stores and the flow straightening influence of the pylons. Fig. 8 presents the lift coefficient curves for all configurations.

Drag coefficient, $\alpha = 12^\circ$. --As at $\alpha = 0^\circ$, the drag shows a consistent increase for all configurations. Taking span station as a constant, the longer stores induce the larger drag increases. When fineness ratio is the constant, the more outboard stores increase the drag coefficient the most, however, for L/D's of 8 and 10 there is only a negligible difference between the drag of stores at 40 and 60 per cent semi-span. The pylons also cause a slight drag rise. With the pylons mounted at 40 or 60 per cent semi-span, the drag rise is larger than when at 22 per cent. Again there being only a slight difference between the drag at these two stations. In all cases the amount of drag increase becomes greater as the model is yawed to larger angles. The drag coefficient curves are shown in Fig. 9.

Pitching moment coefficient, $\alpha = 12^\circ$. --Spanwise location, which in this case also results in a rearward shift of the center of pressure of the stores, causes a more pronounced effect on the pitching moment coefficients than does a change of the fineness ratio at a constant position. It might be expected that as the store is moved aft and outboard, since its center of pressure is moved aft with respect to the balance trunnion, the contribution of the store to the pitching moment would become more negative, or more stabilizing. This, however, is not substantiated by the data obtained in the experiment. The most rearward position of the store did result in a large stabilizing moment, but the center position caused a destabilizing increment larger than that of the most forward (22 per cent station) store position. It is possible that in the mid position, the store has a greater effect on the total wing and causes the entire wing-store combination's center of pressure to shift forward more than when it is mounted at the 22 or 60 per cent semi-span stations. This effect was consistently demon-

strated by all fineness ratios, with one exception. For $L/D = 8$, at Ψ greater than 12° , the logical pattern occurs. The pylons were destabilizing, except in the 60 per cent position at small yaw angles. Since the balance trunnion location coincided with the quarter chord of the mean aerodynamic chord, the pitching moment coefficients shown in Fig. 10 are not only with respect to the trunnion, but are also the pitching moment coefficients about the quarter chord, $C_{M.25}$.

Side force coefficient, $\alpha = 0^\circ$. --In all cases there was a large increase in the side force amounting to approximately three times the stores-off value. The side force, in general, was little affected by either store size or location. There was, however, a trend which can be seen in the $C_{Y\Psi}$ curve of Figs. 23 and 25. As the stores are moved outboard, there is a slight increase in $C_{Y\Psi}$ for constant length missiles. However, when position is held constant, the store of $L/D = 10$ yields the smallest slope, the slopes for fineness ratios of eight and twelve being very close to equal and only slightly higher than for the $L/D = 10$ store. The stores-on side force curve shows one of the largest increases over the store-off curves of all the lateral coefficients, but is the least sensitive to store location and size. In this, and all following cases, the slope of the coefficient curves was read at $\Psi = 4^\circ$, since the data were somewhat inaccurate near zero in many cases.

Side force coefficient, $\alpha = 12^\circ$. --What has already been stated with respect to the side force coefficient at $\alpha = 0^\circ$ is also true for $\alpha = 12^\circ$, although the slope changes are more pronounced at the higher angle of attack when the store parameters are altered. The increase in $C_{Y\Psi}$ is larger when either position or fineness ratio is taken as a constant, and

the spread between $C_{Y\dot{\Psi}}$ curves is greater at the higher angle of attack. One major difference between side force coefficients at $\alpha = 0^\circ$ and $\alpha = 12^\circ$ is that $C_{Y\dot{\Psi}}$ now increases as the store fineness ratio increases, the store of $L/D = 12$ resulting in the largest change of slope. Another noticeable trend was that the longer stores, at any one station, produced the greatest change in the side force. If the fineness ratio is fixed, the largest change results from stores nearer the wing tips. Figs. 24 and 26 illustrate these slope trends. A study of Figs. 11 through 22 will show the changes in side force magnitude when the store parameters are altered and the model is yawed.

Yawing moment coefficient. --This is the most critical of all the forces and moments with respect to variations of the store parameters. No attempt will be made to discuss separately the curves for $\alpha = 0^\circ$ and $\alpha = 12^\circ$. The same trends are demonstrated by each, there being only small differences in magnitude between the results at the two angles. While the effect of the store fineness ratio is noticeable, the location of the missile has the greatest effect on the yawing moment. Again, as in the case of the pitching moment, the chordwise location of the center of pressure has the primary effect on the stores' contribution to the total yawing moment. The curves of C_n versus $\dot{\Psi}$ at constant L/D ratios, Figs. 11 through 16, show that by proper chordwise location of the missiles with respect to the moment center the slope of the yawing stability curve can be made more positive or more negative, even to the point of changing the slope of the curve to a negative, or stable value. If desired, it appears that the influence of the stores on the clean airplane can be nullified by careful selection of the stores' position and fineness ratio. Again note that

the slopes presented in Figs. 23 through 26 and discussed throughout this paper were measured at $\Psi = 4^\circ$. At higher values of Ψ the slopes decrease for all coefficients. It is interesting to note in Figs. 23 and 24 that with the stores mounted near the wing tips the model is stable to varying degrees, even without the presence of a vertical tail. A study of Figs. 25 and 26 indicates that beyond a specific spanwise location, all stores of a minimum length, and greater, will produce yawing moments capable of stabilizing the entire model without the vertical tail. The exact span station and fineness ratios would in each case depend on the airplane characteristics and the level of directional stability without either tail or stores, and upon the aerodynamic characteristics of the stores actually being used. Figs. 23 through 26 indicate that moving the stores outboard or increasing their length will make the component of the total yawing moment due to the stores more negative. Moving the stores toward the wing tips also shifts their center of pressure aft, so that the force on the store has a different position with respect to the yawing moment center.

Rolling moment coefficient, $\alpha = 0^\circ$. --The rolling moment coefficient, or dihedral effect C_{L_y} , is primarily effected by the spanwise location of the stores and to a lesser degree by the fineness ratio of the stores. At the zero angle of attack the wing was operating at a small negative C_L , stores-off and stores-on when in yaw. Thus the rolling moment which would have theoretically been equal to zero if $C_L = 0$ for this symmetric, mid-wing model without stores was actually slightly negative, indicating a left roll. At $\alpha = 0^\circ$ the stores in the two outboard positions contributed negative rolling moment increments to the clean configuration curve,

while the inboard stores added a positive increment. The change in flow pattern around the fuselage is possibly the cause of this change as the store is moved in toward the centerline. This trend also appears in C_{l_y} as shown in Figs. 23 and 25. The rolling moment coefficient curves for $\alpha = 0^\circ$ are plotted against Ψ in Figs. 11 through 13 and Figs. 17 through 19.

Rolling moment coefficient, $\alpha = 12^\circ$. --At $\alpha = 12^\circ$ there was little change in the rolling moment derivative for changes in span location or fineness ratio as compared to the stores-off curve for the wing-fuselage combination. There is a negative displacement and rotation of the curves which is more apparent with position change than with L/D change. This again is probably due to the interference effect of the fuselage, and diminishes as the stores are moved toward the wing tips. At constant span position the curves for the different store lengths group together with little spread, whereas the curves for different station, constant fineness ratio, tend to spread out with the outermost stores causing the greatest negative displacement. This pattern can be verified by examining Figs. 14 through 16 and Figs. 20 through 22. The pylons alone shift the clean curve slightly negatively, noticeably increasing the slope at low angles of yaw. The changes in dihedral effect can be seen in Figs. 24 and 26 for $\alpha = 12^\circ$.

Coefficient curves in general. --The coefficient curves in general all show a slope change in the range of $\Psi = 10^\circ$. It is felt that the change is due to the blanketing effect of the fuselage as the trailing wing panel is rotated more and more into the wake of the fuselage by increasing yaw. The change is very obvious in some of the coefficient curves, especially C_Y for the clean configuration at $\alpha = 12^\circ$.

Theoretically all lateral coefficient curves should have passed through zero at zero yaw. However, due to slight inaccuracies in the model and the direction of the airflow, very few actually passed through the origin. Although the error is considered small, the lateral derivatives were measured at $\Psi = 4^\circ$. The possibility of some stream rotation is indicated by the initial displacement of the rolling moment coefficient curves. Since this project was aimed primarily at determining the changes involved when the two store parameters are varied and the model yawed, these small curve displacements were ignored, especially when only slopes were being considered. Numerical values of the static lateral derivatives can be found in Table I for $\alpha = 0^\circ$ and $\alpha = 12^\circ$; $\Psi = 4^\circ$.

Although in actual operation the pylons would probably be jettisoned, there may be, however, some instances when they are retained. For this reason, the effect of the pylons has been briefly noted and the more important curves relating to them have been presented in the appendix.

Dynamic effects. --The primary purpose of this study has been the determination of the static stability coefficient and derivatives. It is felt by the author that complete analysis of these large store effects should also include mention of the effect on dynamic stability, since the static coefficients appear in the dynamic equations. The pronounced effect of the stores on the yawing moment has already been noted, likewise the relatively small effect on the rolling moment at $\alpha = 12^\circ$. Using an empirical relation given by Perkins and Hage¹ we see that at $\alpha = 12^\circ$ the model has an

¹Perkins, Courtland D. and Hage, Robert E., Airplane Performance Stability and Control, New York: John Wiley and Sons, Inc., 1949, p. 343.

effective dihedral angle of over 13° due to the rolling derivative alone where $0.0002 \Gamma_{\text{eff}} = C_{l_y}$. At $\alpha = 0^\circ$ the effective dihedral angle is less than 3.5° . This high value at $\alpha = 12^\circ$ coupled with poor directional stability which could result from placing the store too far forward could result in a strong Dutch roll which would be objectionable during low-speed operations such as landing. The presence of these large heavy bodies located at some distance from the aircraft centerline also increases the moment of inertia about the roll and yaw axes further reducing the damping which is already low due to the large dihedral effect. At $\alpha = 0^\circ$ the dihedral effect is small, indicating from this viewpoint alone, that the high speed flight would be of a satisfactory nature.

These are by no means the only possible results of improper location of the stores, the dynamic cross derivatives C_{l_r} and C_{n_p} for example have not been considered. The brief mention of dynamic effects should, however, serve to point out that for a complete analysis the investigation can not be limited to only static considerations.

CHAPTER V

CONCLUSIONS

On the basis of this investigation, the following conclusions have been reached.

1. All six of the major aerodynamic forces and moments are affected in yaw by the presence of large external bodies affixed to the wing. The longitudinal coefficients are not as greatly changed as are the lateral coefficients and derivatives.

2. The effects of the stores are controllable to some degree in all cases by the selection of the store's fineness ratio and spanwise location.

3. The yawing moment is especially sensitive to the location with respect to the aircraft's center of gravity of the center of pressure of the store. The yawing moment increment due to the store can be made either stabilizing, destabilizing or simply neutral as a function of its spanwise location. In this investigation, a movement spanwise was accompanied by an implicit chordwise change with respect to the MAC.

4. The effect of such large external bodies on the low speed directional stability is large enough to warrant intensive study before any such installation is made.

5. There appears to be some interference from the fuselage when the store is mounted adjacent to it.

APPENDIX

TABLE I

NUMERICAL VALUES OF LATERAL DERIVATIVES

$$\Psi = 4^\circ$$

$$\alpha = 0^\circ$$

$$\alpha = 12^\circ$$

L/D	%2y/b	C_{Y_Ψ}	C_{n_Ψ}	C_{l_Ψ}	C_{Y_Ψ}	C_{n_Ψ}	C_{l_Ψ}
Clean		0.00371	0.00111	-0.00013	0.00215	0.00052	0.00345
12	22	0.00976	0.00176	+0.00014	0.00741	0.00170	0.00270
12	40	0.01025	0.00058	-0.00026	0.00852	0.00000	0.00294
12	60	0.01025	-0.00139	-0.00058	0.00890	-0.00208	0.00270
10	22	0.00952	0.00195	+0.00031	0.00742	0.00204	0.00333
10	40	0.00975	0.00080	-0.00020	0.00800	0.00043	0.00333
10	60	0.01000	-0.00083	-0.00068	0.00832	-0.00141	0.00286
8	22	0.01004	0.00222	+0.00060	0.00690	0.00213	0.00333
8	40	0.01013	0.00118	-0.00010	0.00702	0.00109	0.00312
8	60	0.01050	-0.00058	-0.00062	0.00727	-0.00059	0.00294

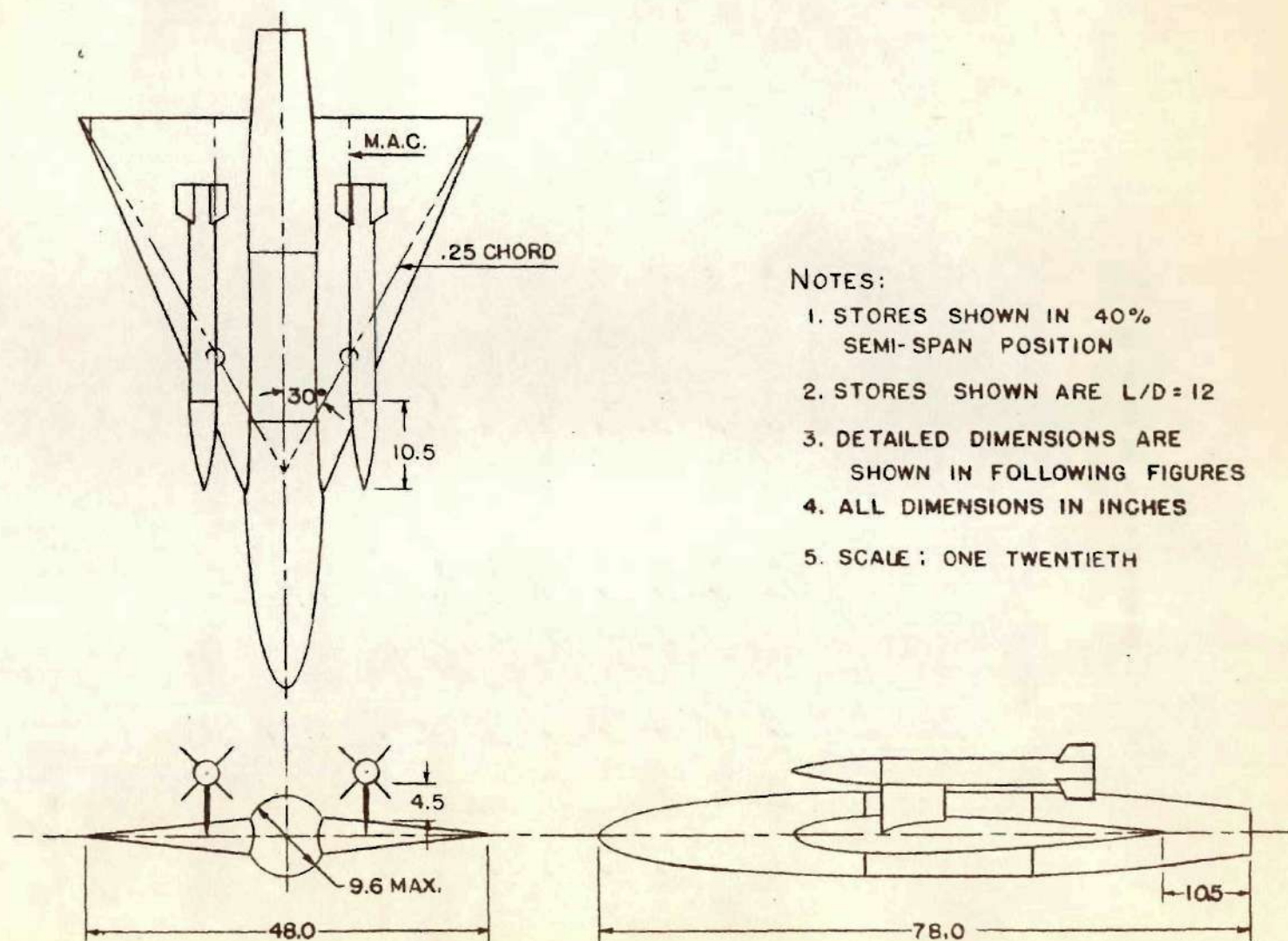
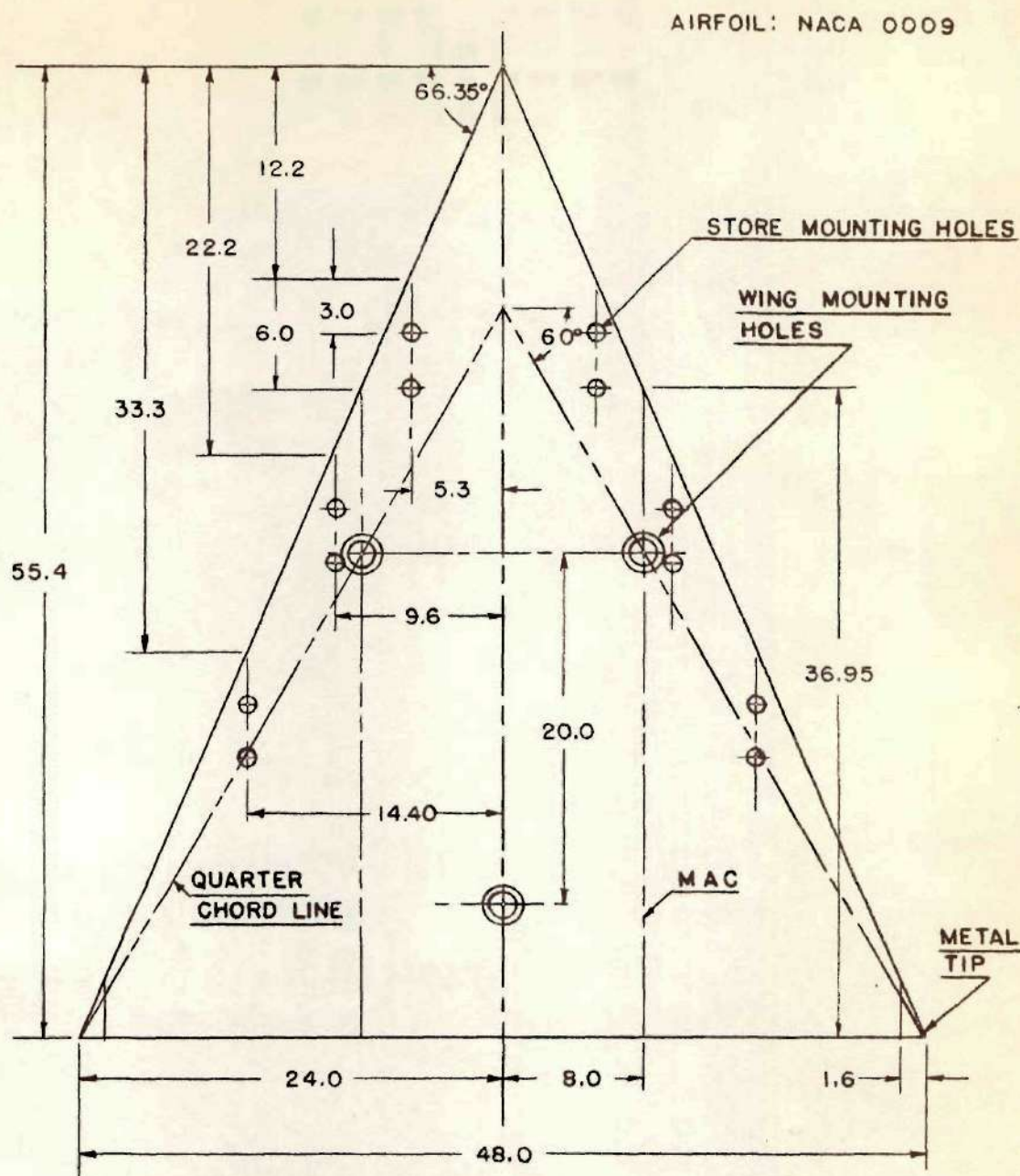


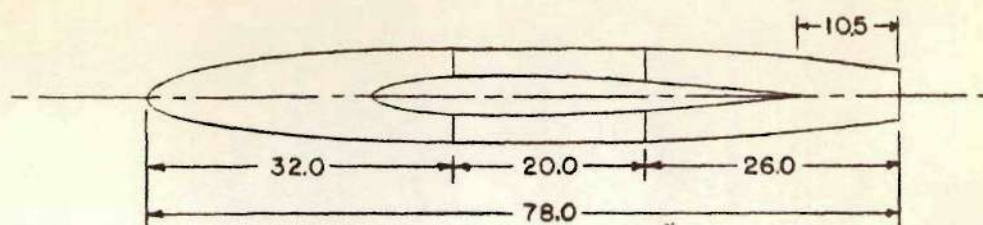
FIG. 1

ASSEMBLED DELTA-WING MODEL



ALL DIMENSIONS IN INCHES EXCEPT AS NOTED
SCALE: ONE TENTH

FIGURE 2
DIMENSIONS OF DELTA



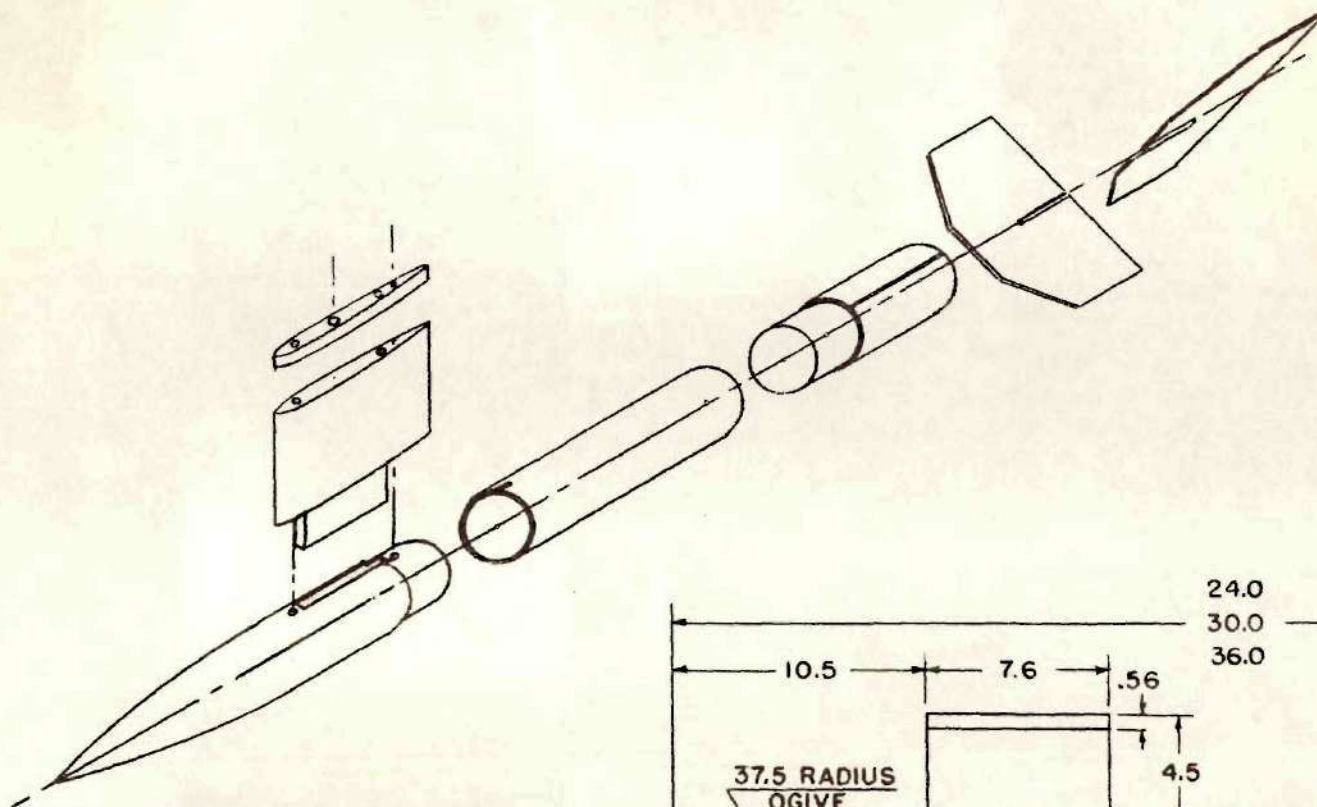
FUSELAGE - SIDE VIEW

ORDINATES
IN INCHES

STATION	RADIUS
0.	0.
0.4	0.78
0.6	0.94
1.0	1.19
2.0	1.63
4.0	2.25
6.0	2.72
8.0	3.10
12.0	3.70
16.0	4.14
24.0	4.68
32.0	4.79
52.0	4.79
60.0	4.38
68.0	3.64
76.0	2.68
78.0	2.50
L.E. RAD.	0.83

FUSELAGE DIMENSIONS

FIG. 3



NOTE:
 1. TAIL SECTION ROTATED
 45° TO SHOW FINS IN
 TRUE PROJECTION
 2. ALL DIMENSIONS INCHES

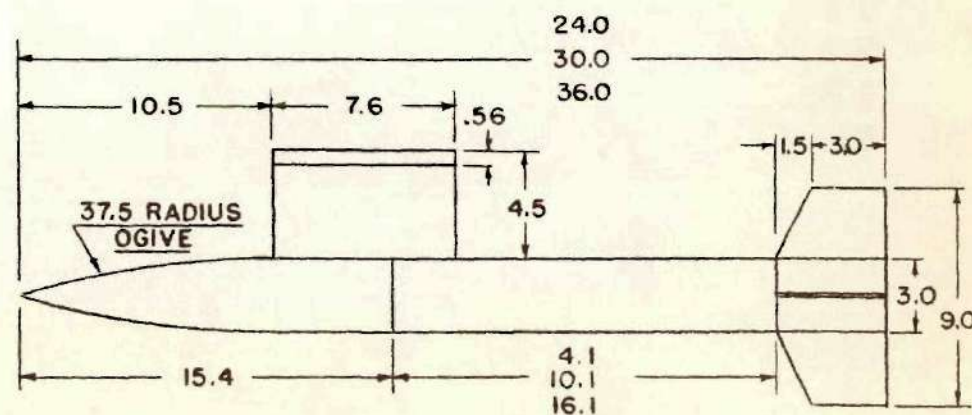


FIGURE 4
EXTERNAL STORE

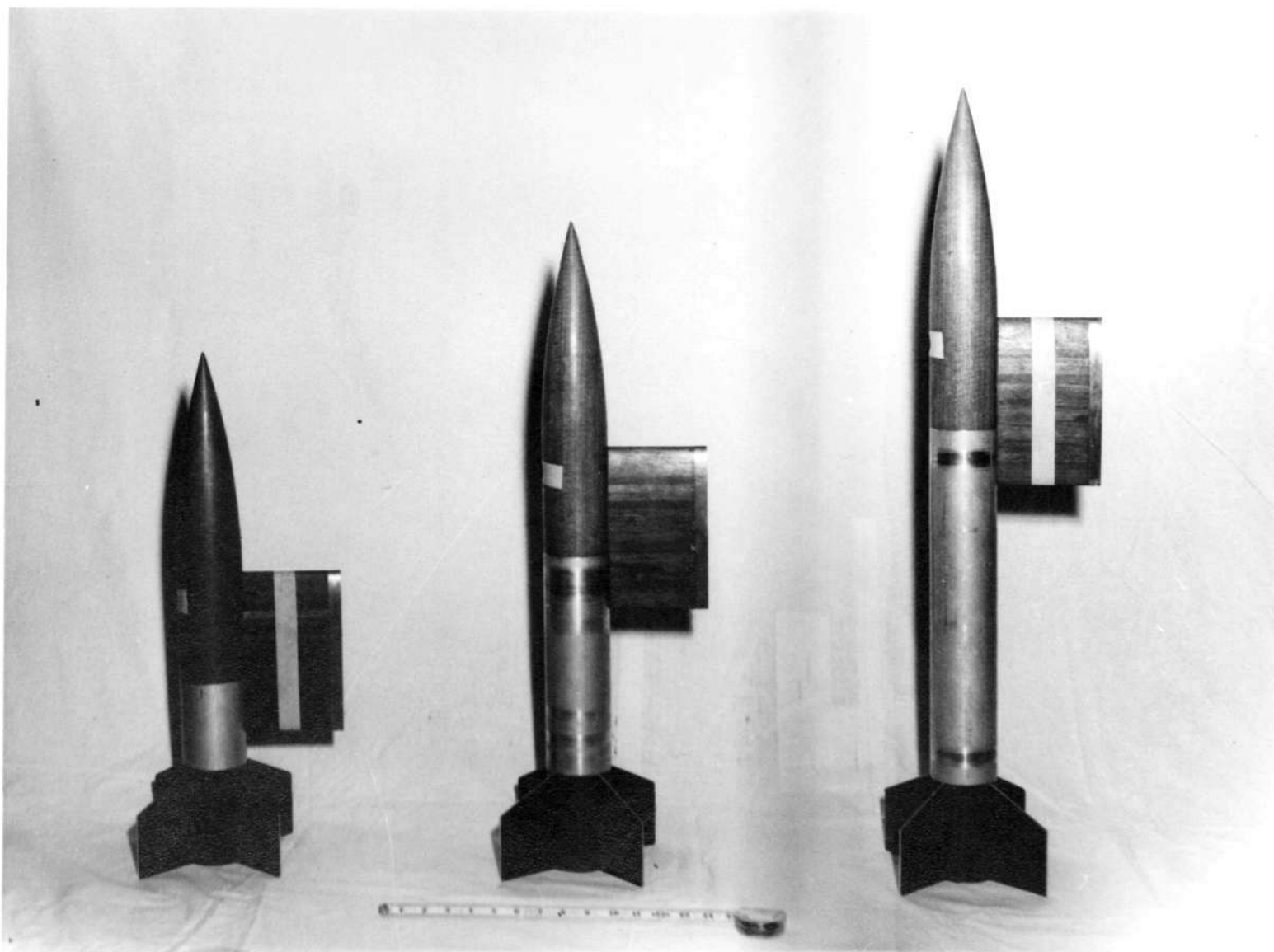


Fig. 5
Photograph of External Stores

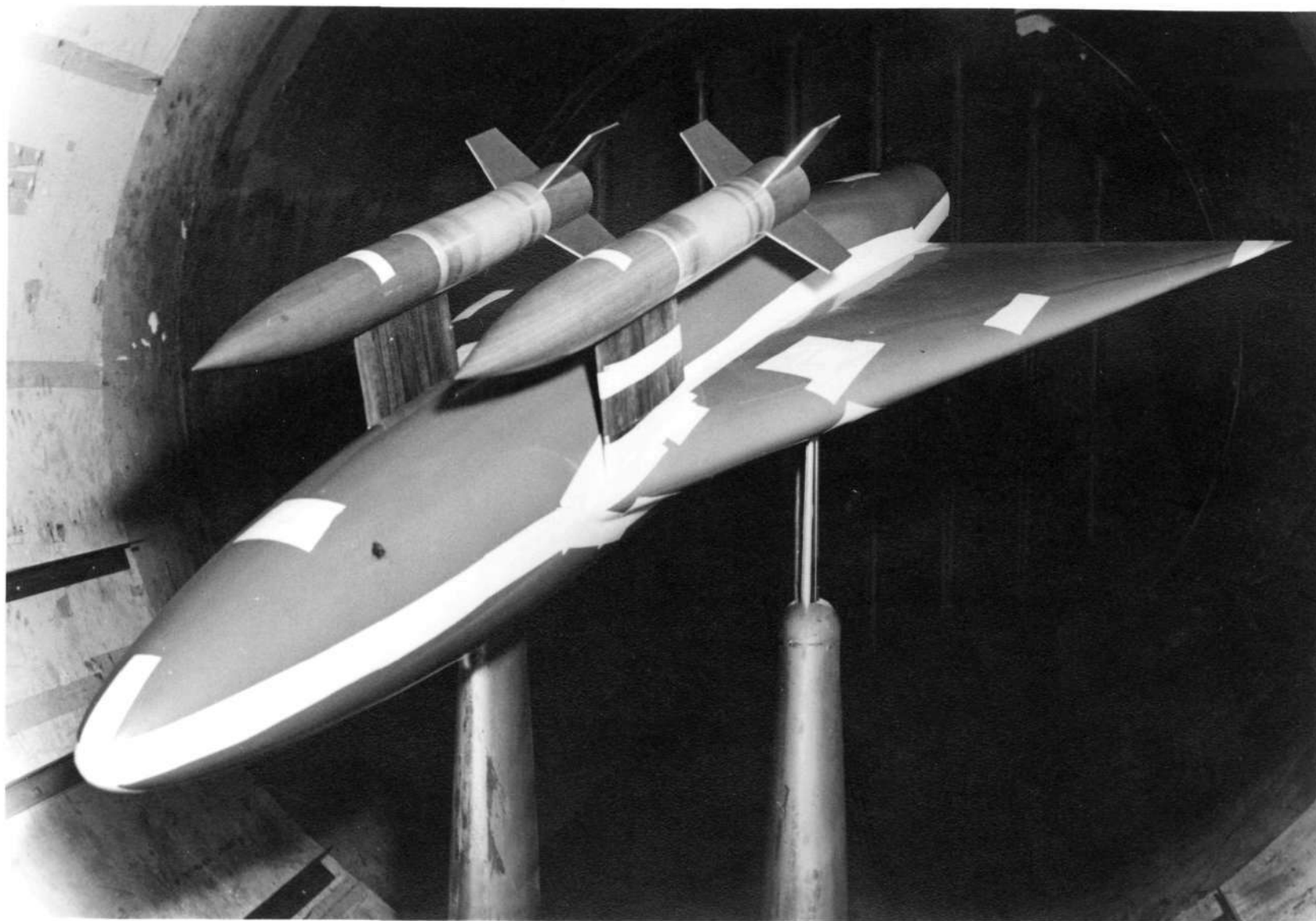
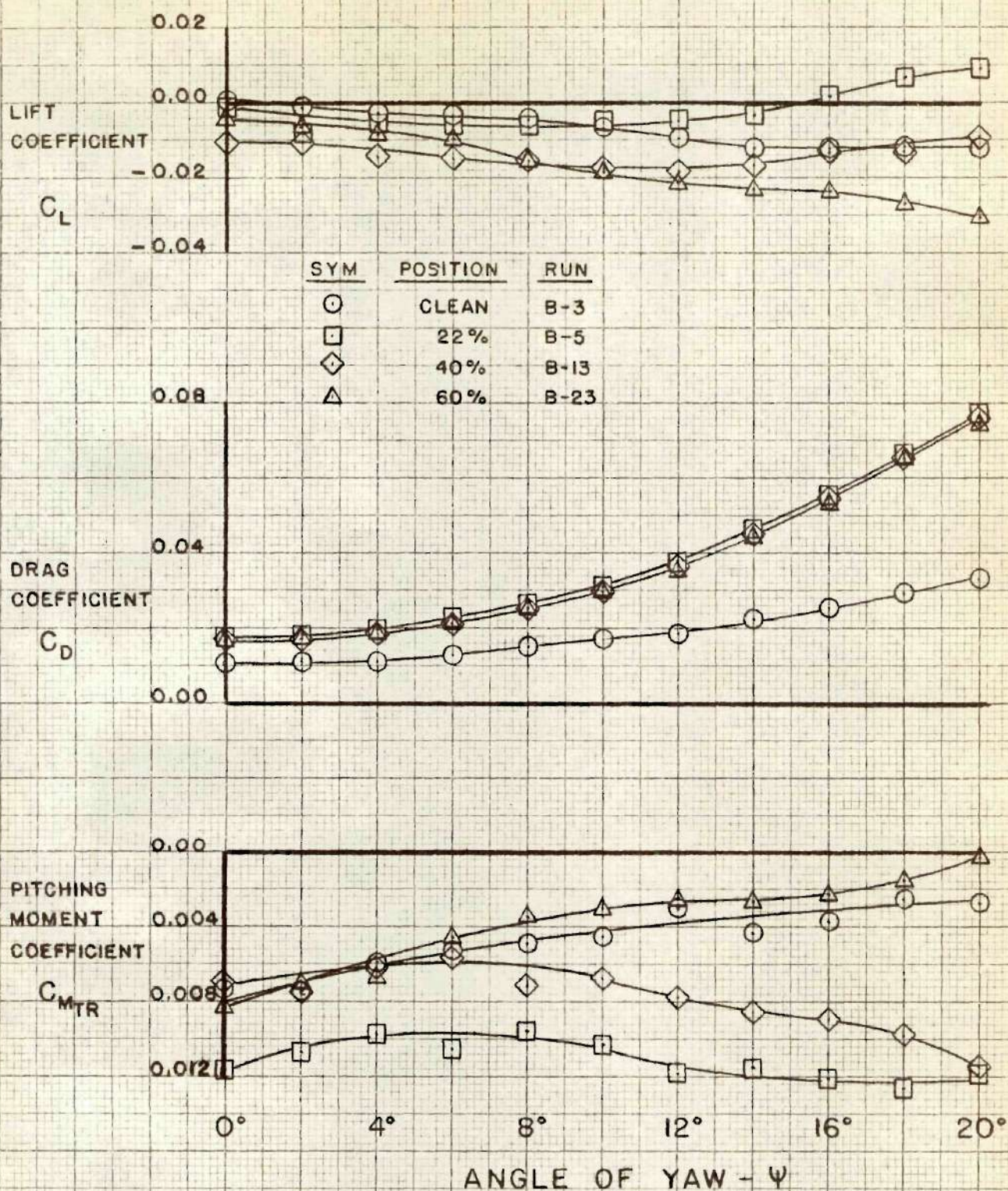
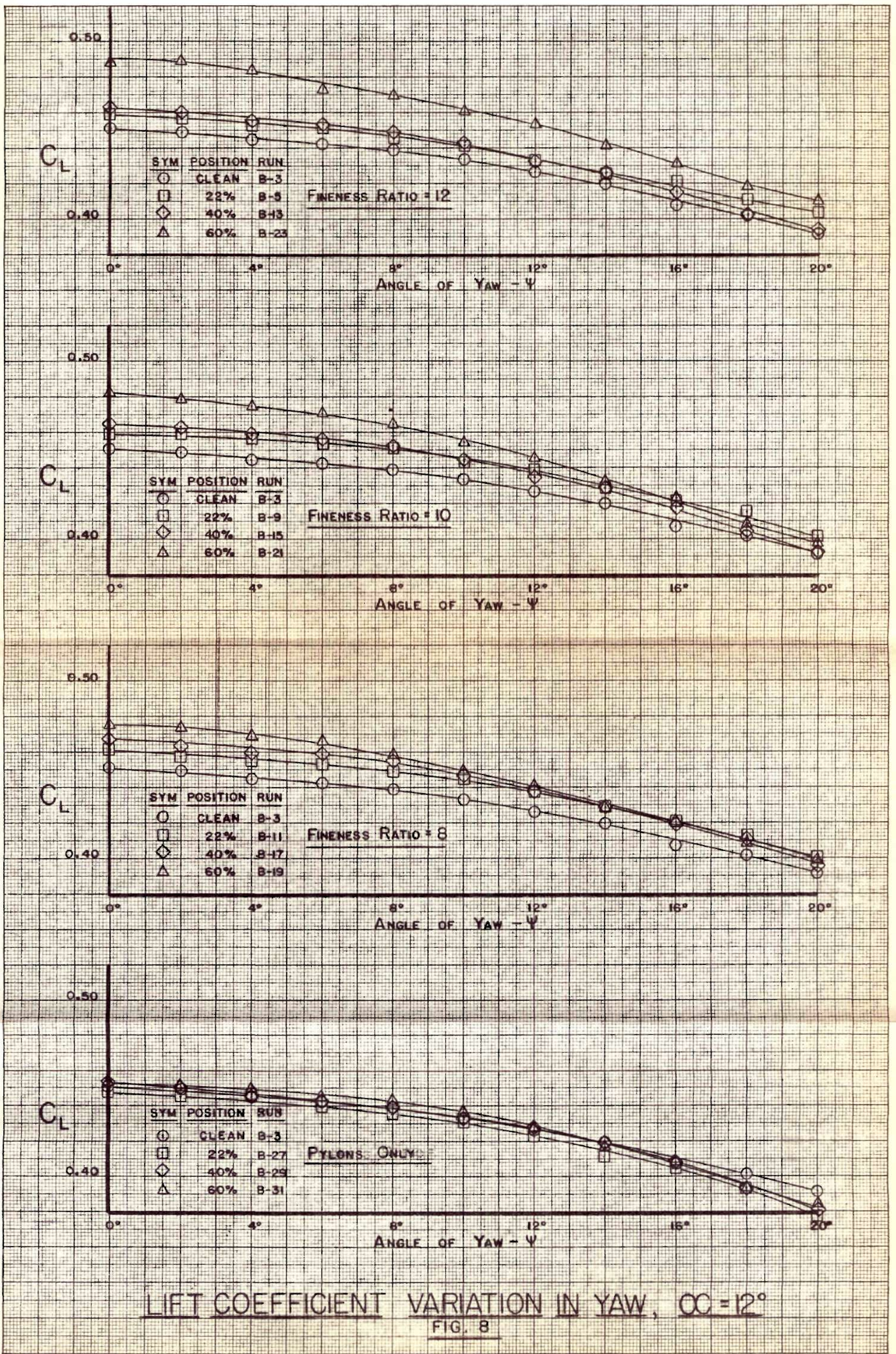


Fig. 6
View of Complete Model Mounted in Tunnel

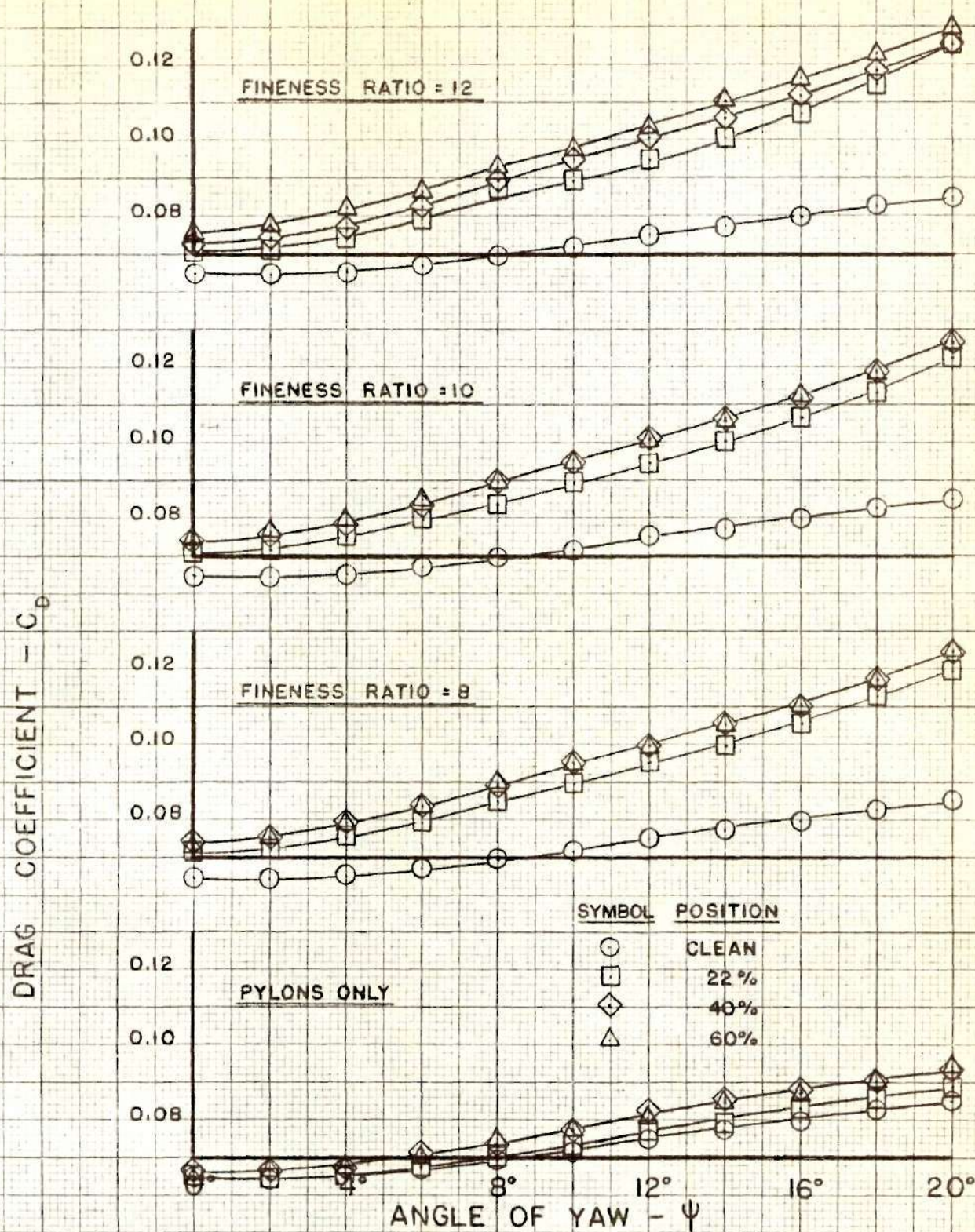


VARIATION OF LONGITUDINAL DERIVATIVES IN YAW
 FINENESS RATIO = 12, $\alpha = 0^\circ$

FIG. 7

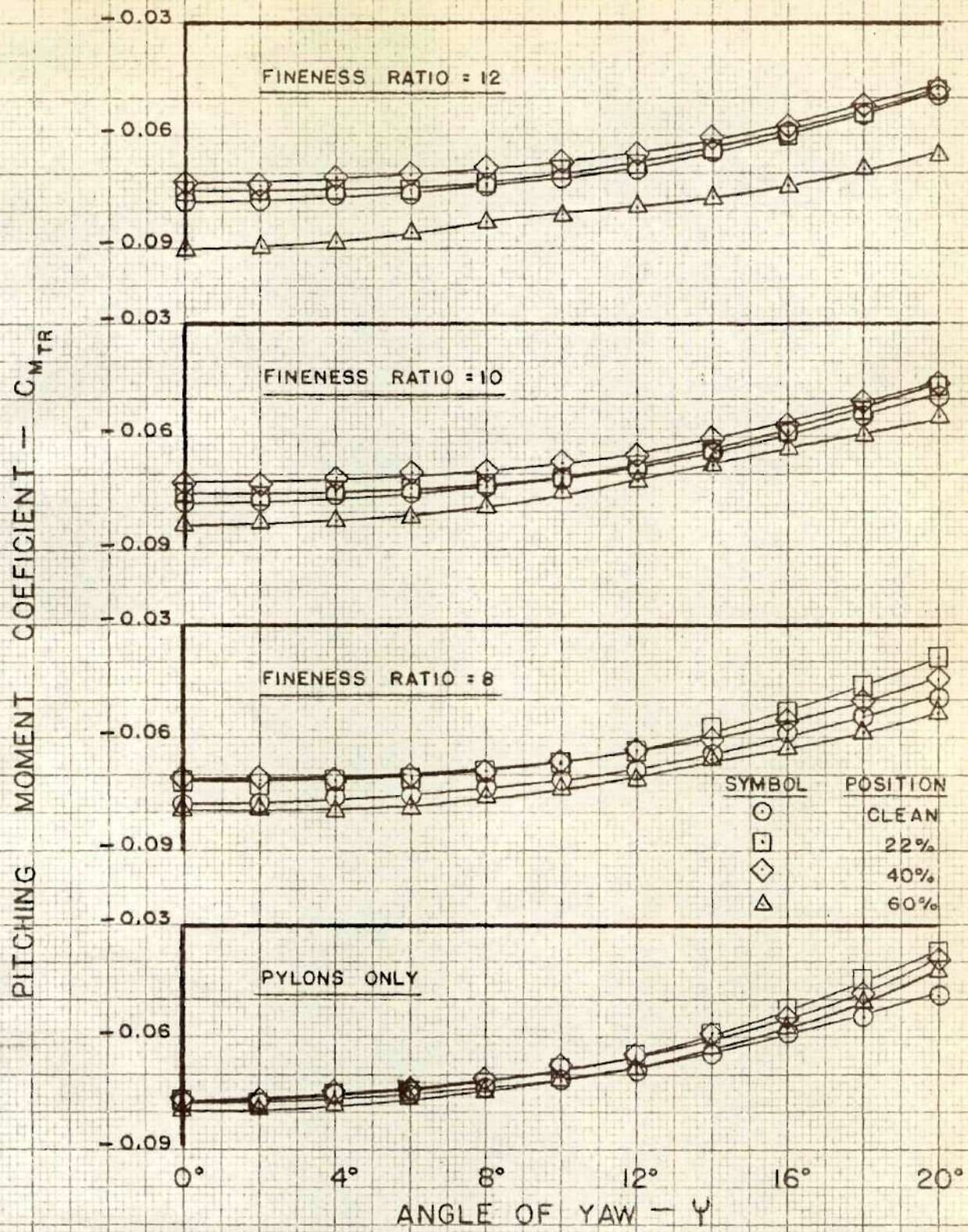


LIFT COEFFICIENT VARIATION IN YAW, $\alpha = 12^\circ$
 FIG. 8



DRAG COEFFICIENT VARIATION IN YAW, $\alpha = 12^\circ$

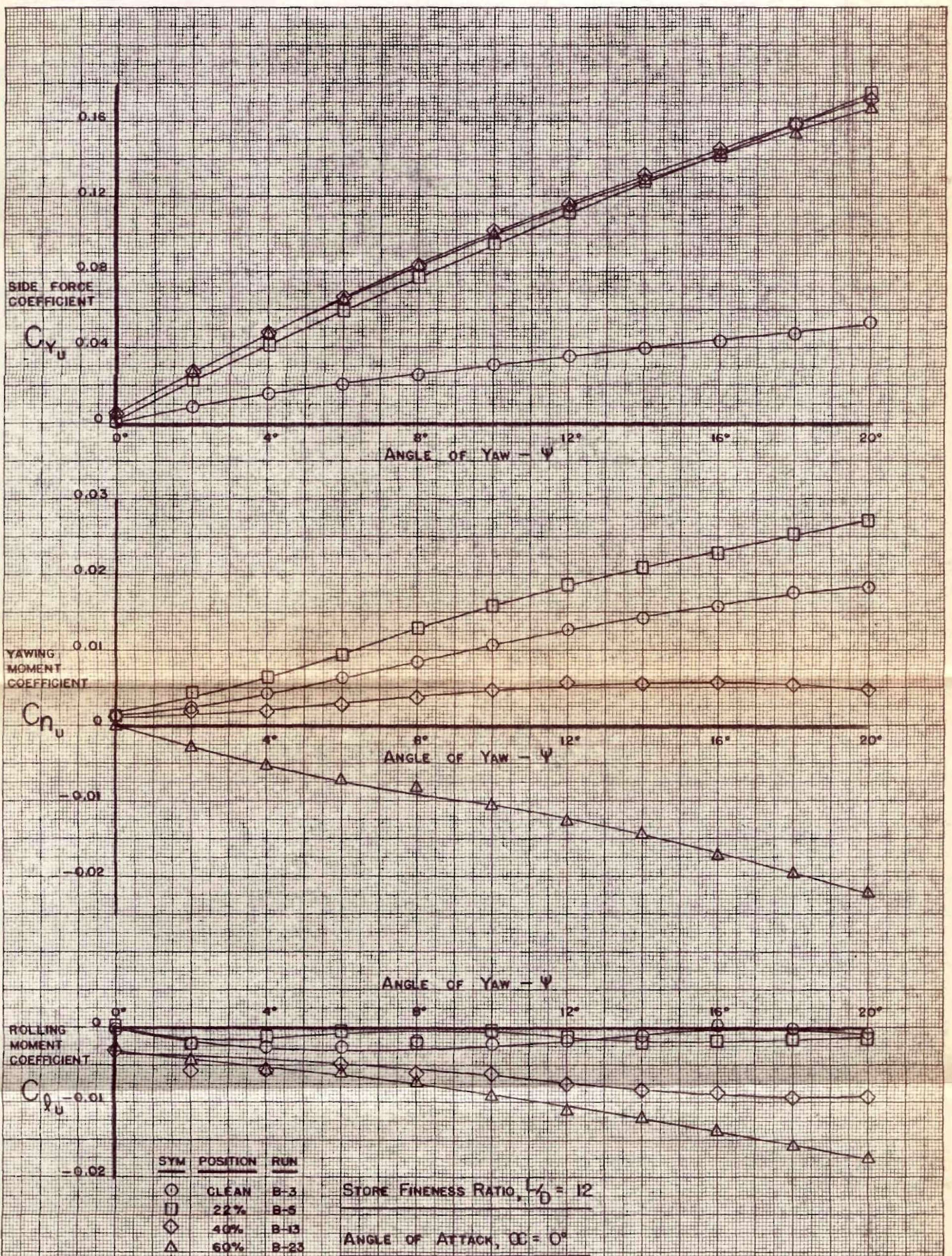
FIG. 9



PITCHING MOMENT COEFFICIENT VARIATION IN YAW

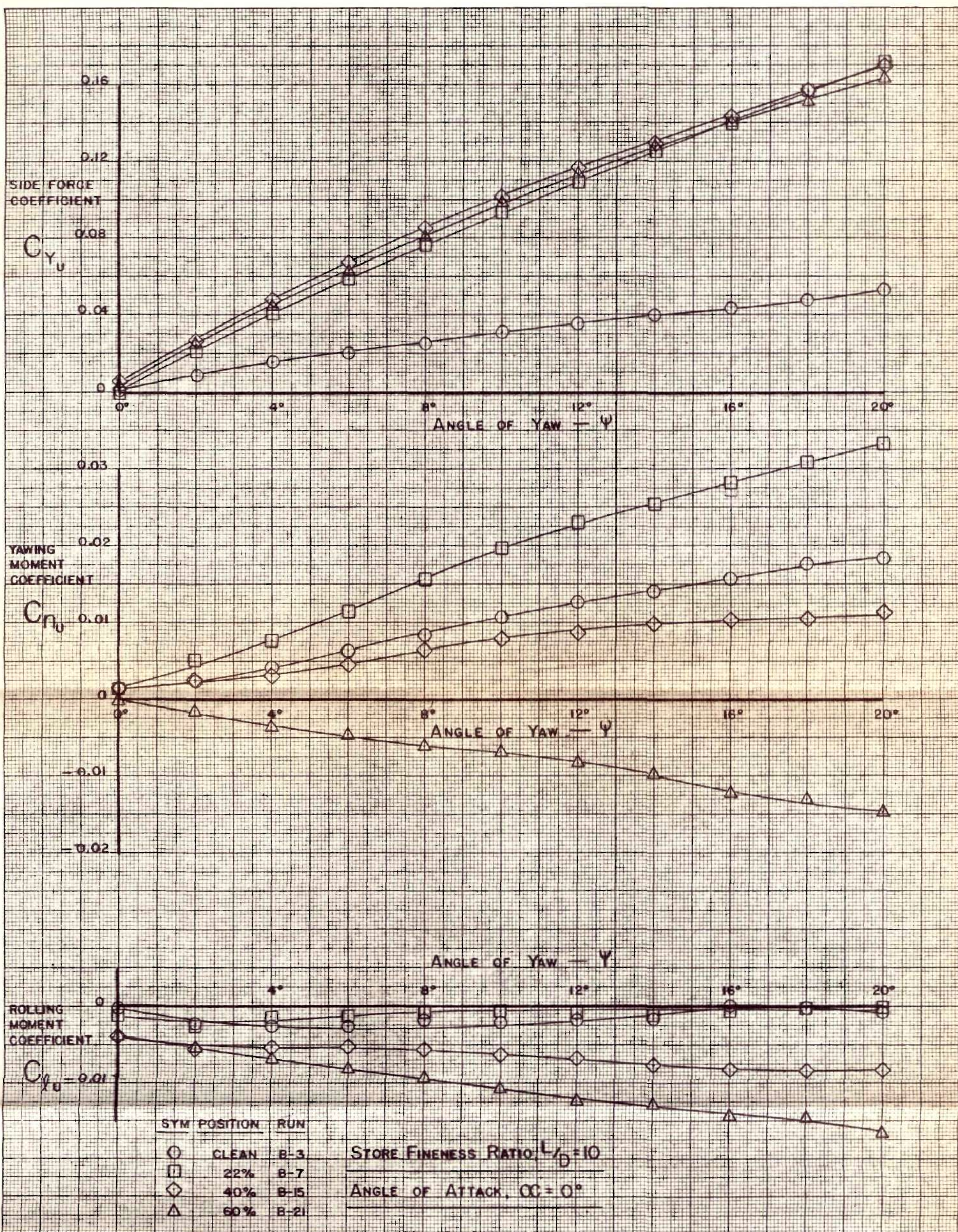
$\alpha = 12^\circ$

FIG. 10



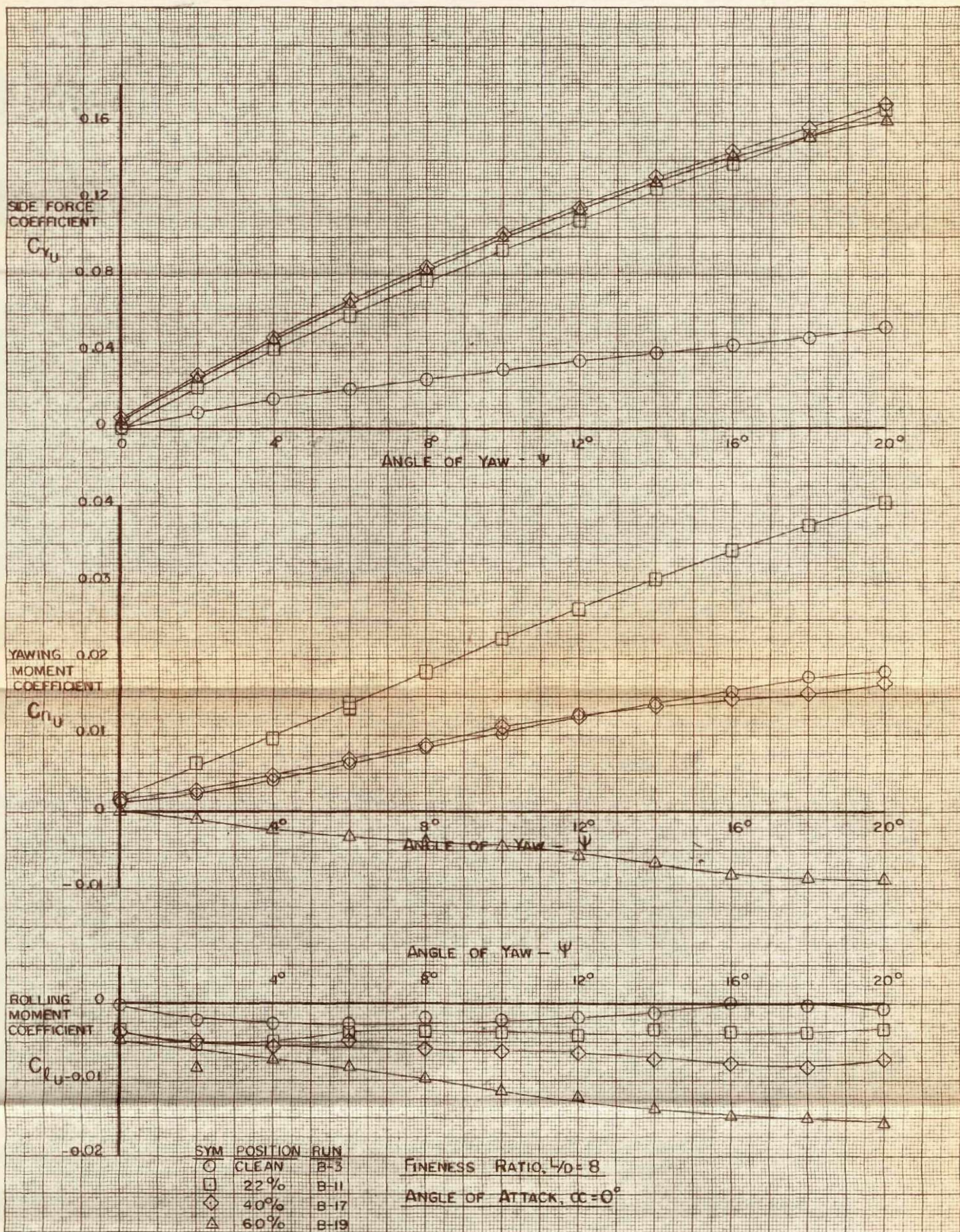
LATERAL DERIVATIVES IN YAW

FIG. 11



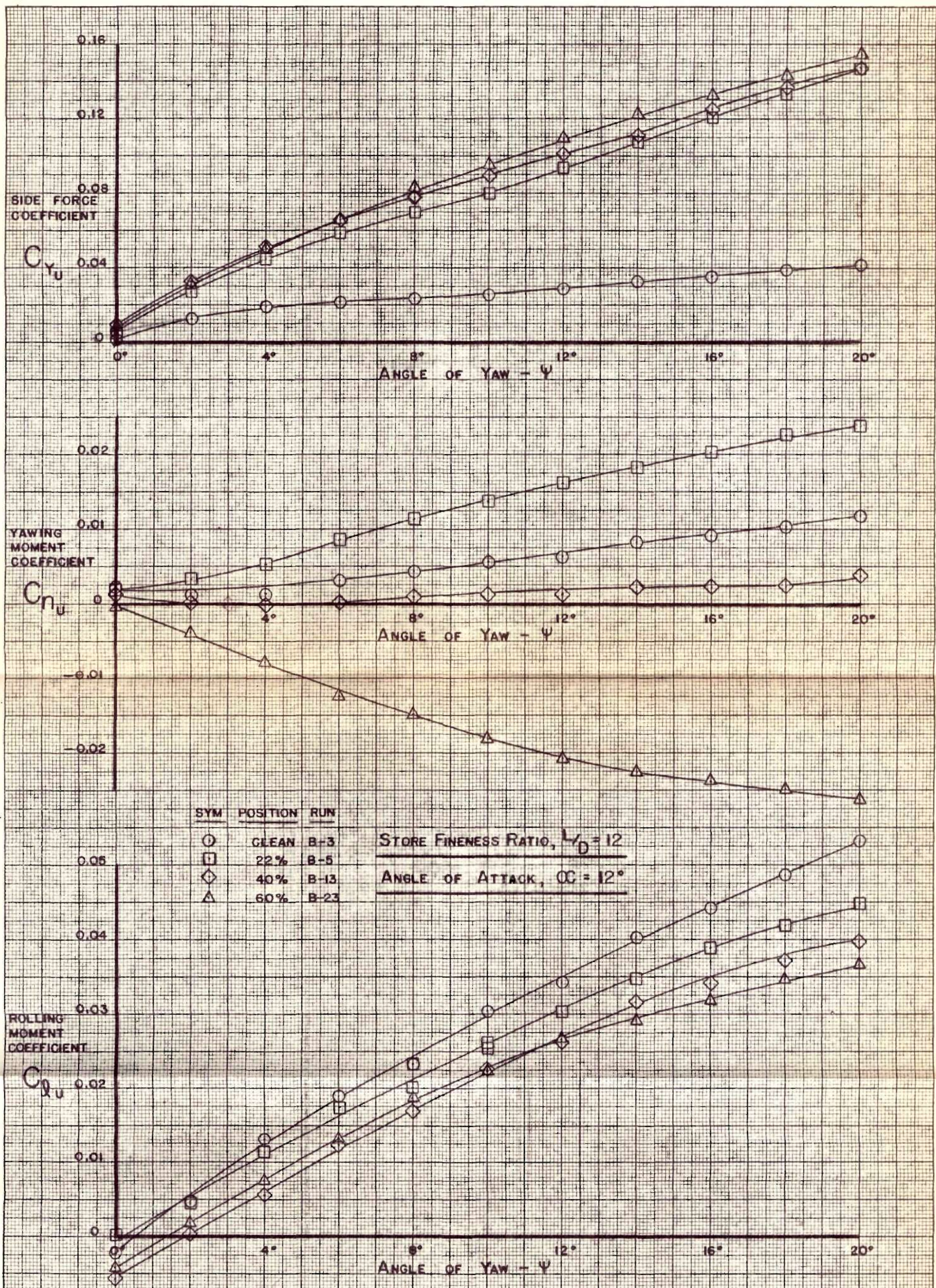
LATERAL DERIVATIVES IN YAW

FIG. 12



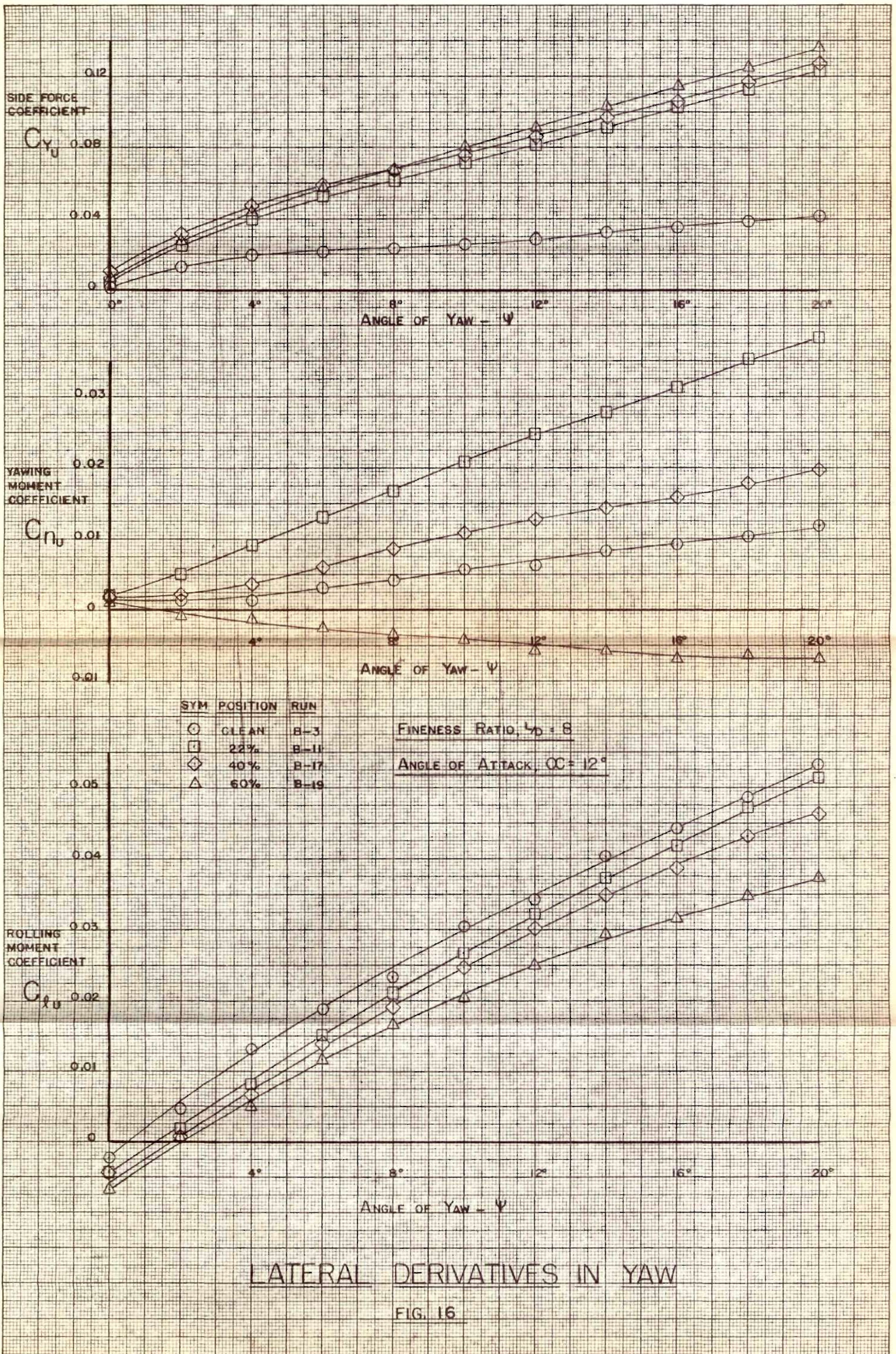
LATERAL DERIVATIVES IN YAW

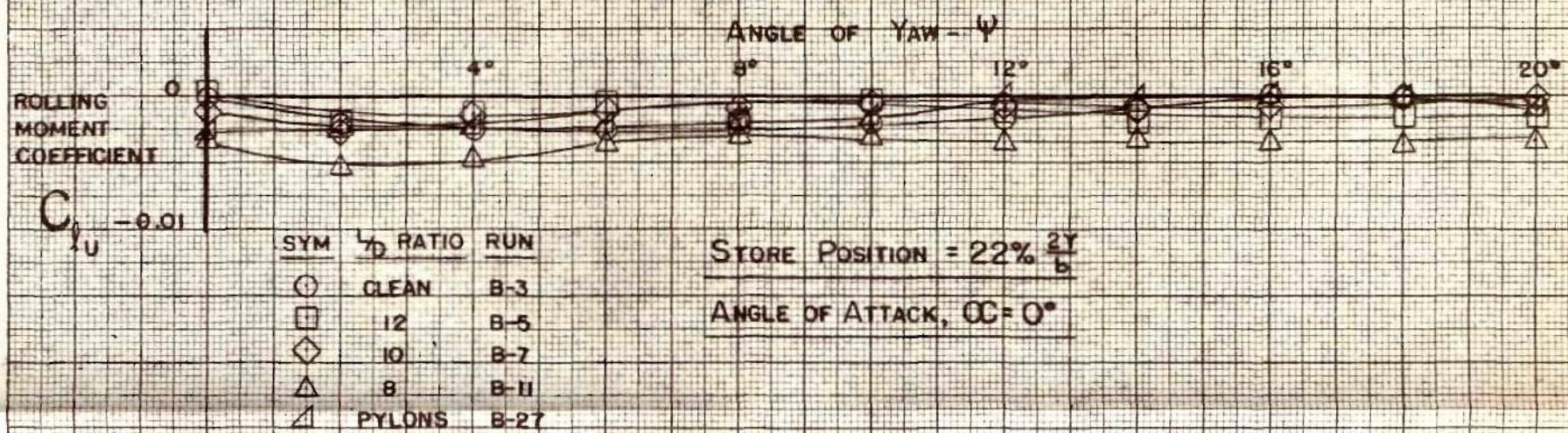
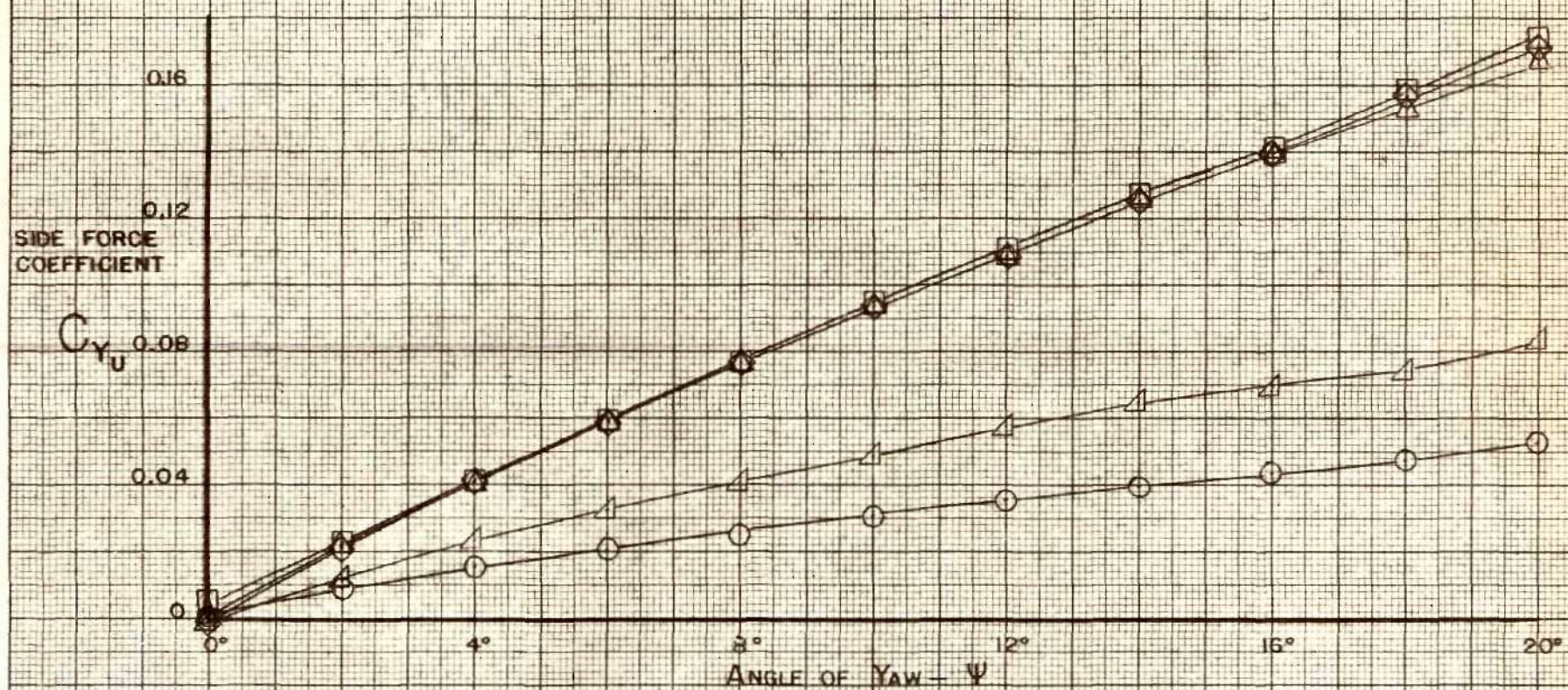
FIG. 13



LATERAL DERIVATIVES IN YAW

FIG. 14



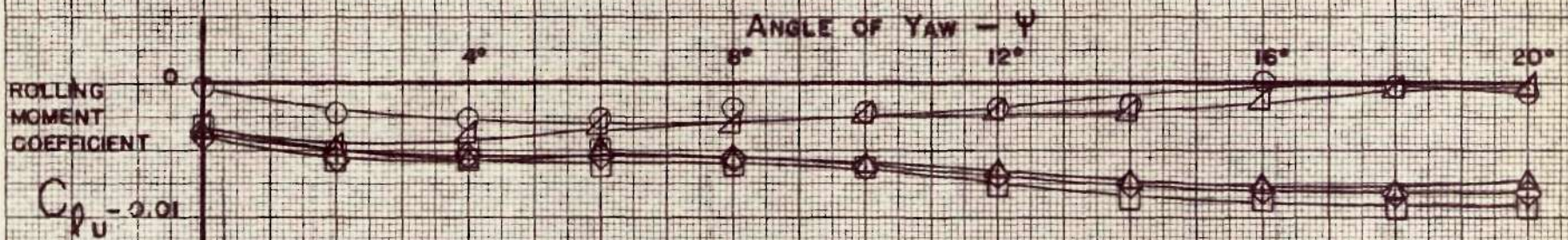
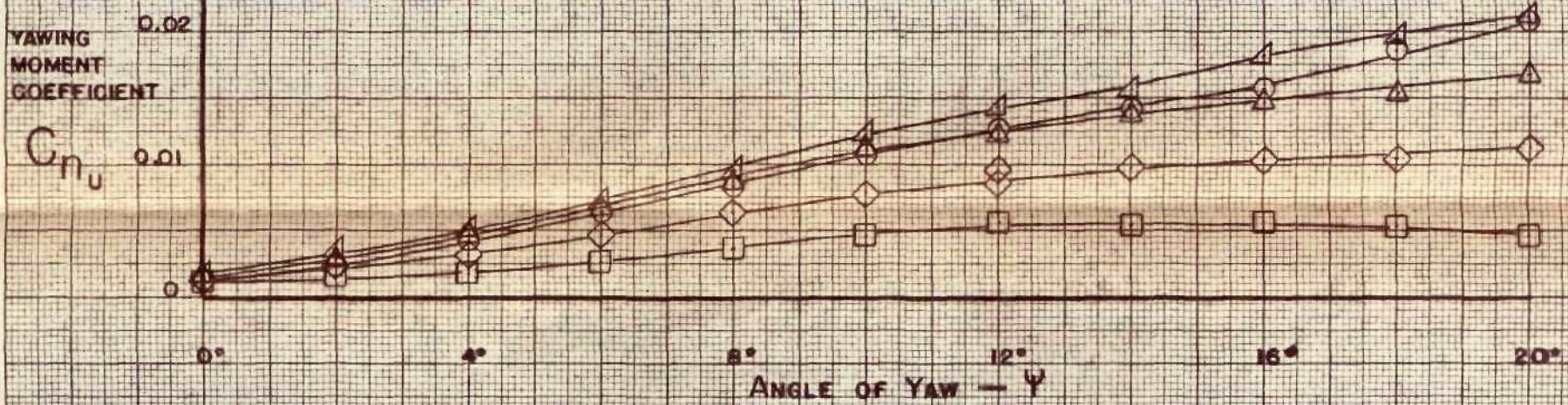
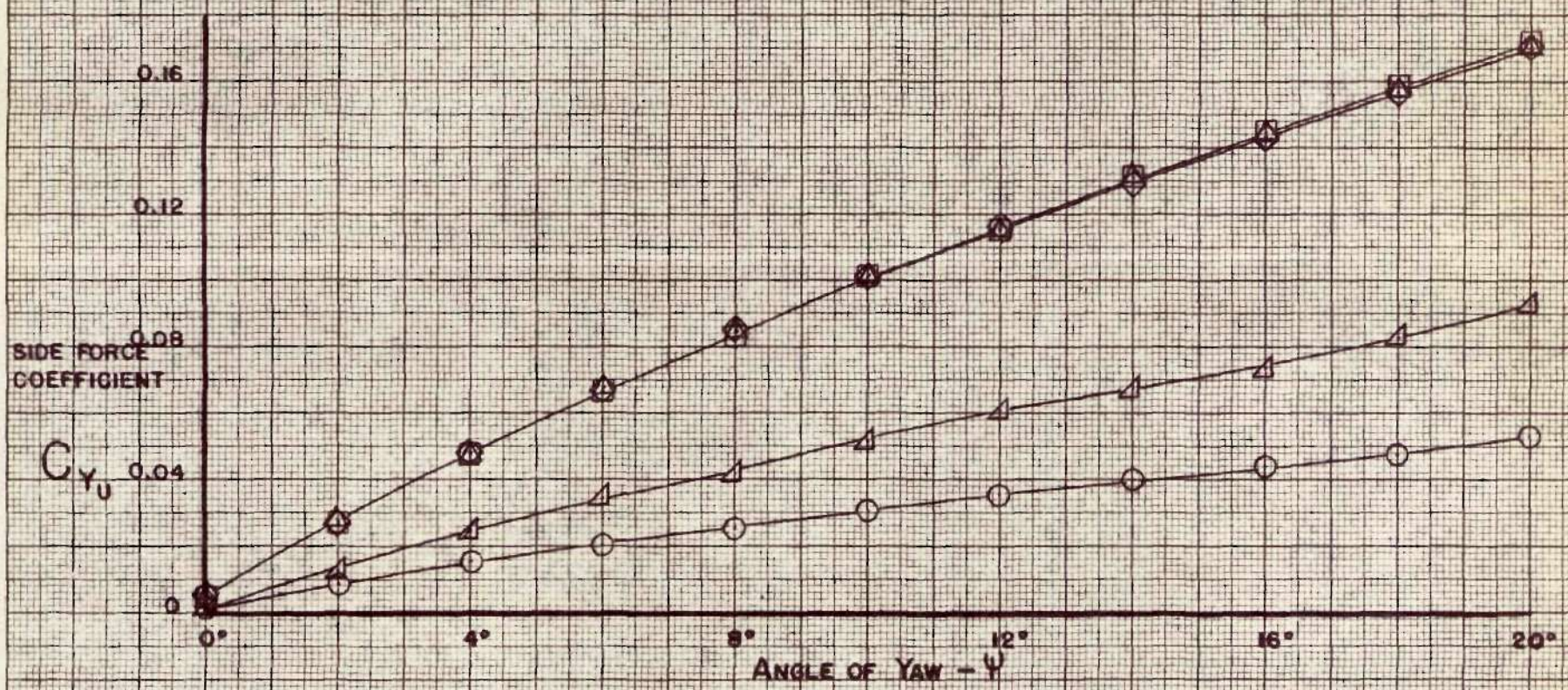


SYM	L/D RATIO	RUN
○	CLEAN	B-3
□	12	B-5
◇	10	B-7
△	8	B-11
▽	PYLONS	B-27

STORE POSITION = 22% $\frac{2Y}{b}$
 ANGLE OF ATTACK, $\alpha = 0^\circ$

LATERAL DERIVATIVES IN YAW

FIG. 17

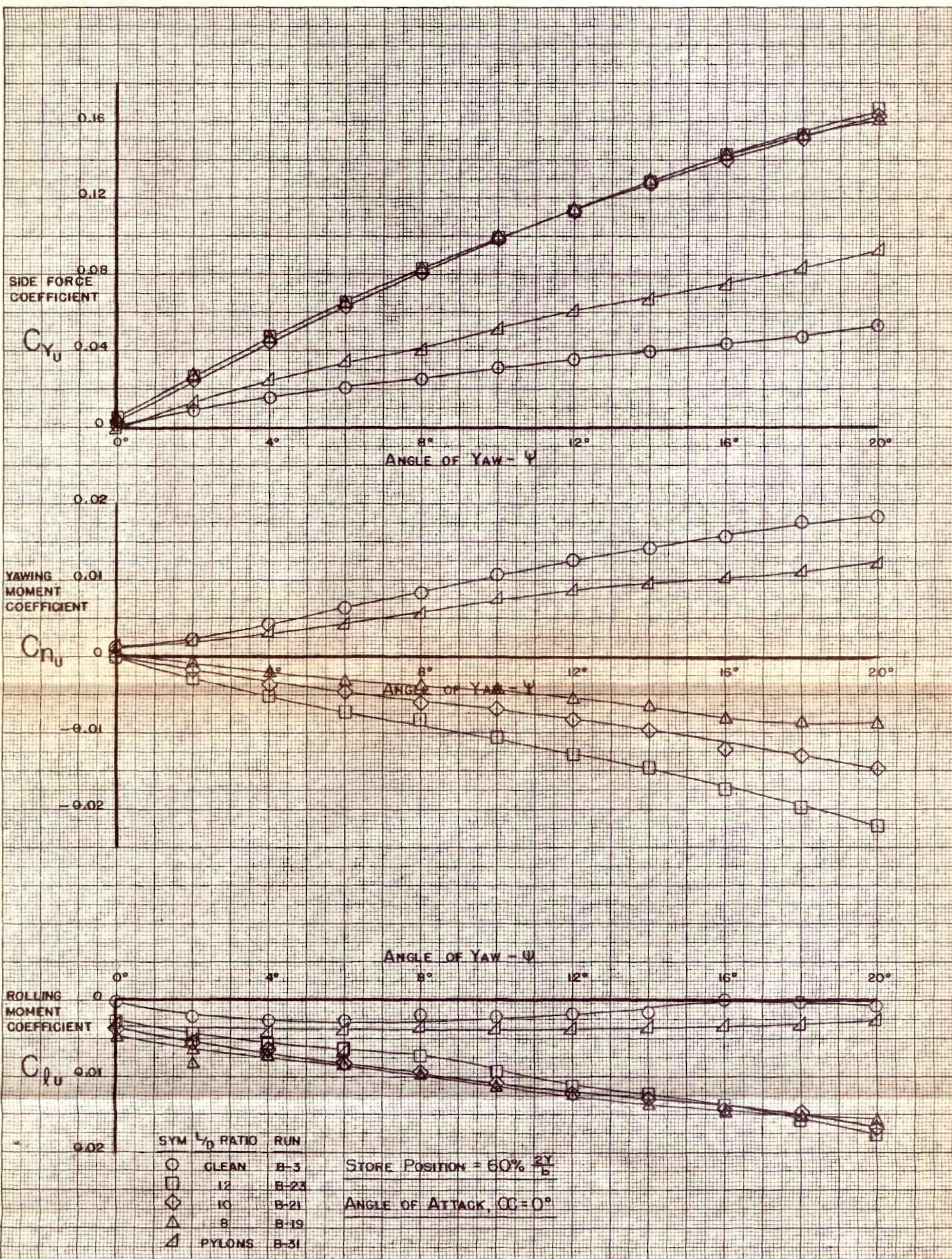


SYM	L/D RATIO	RUN
○	CLEAN	B-3
□	12	B-13
◇	10	B-15
△	8	B-17
▲	PYLONS	B-29

STORE POSITION = 40% $\frac{2Y}{D}$ ANGLE OF ATTACK, $\alpha = 0^\circ$

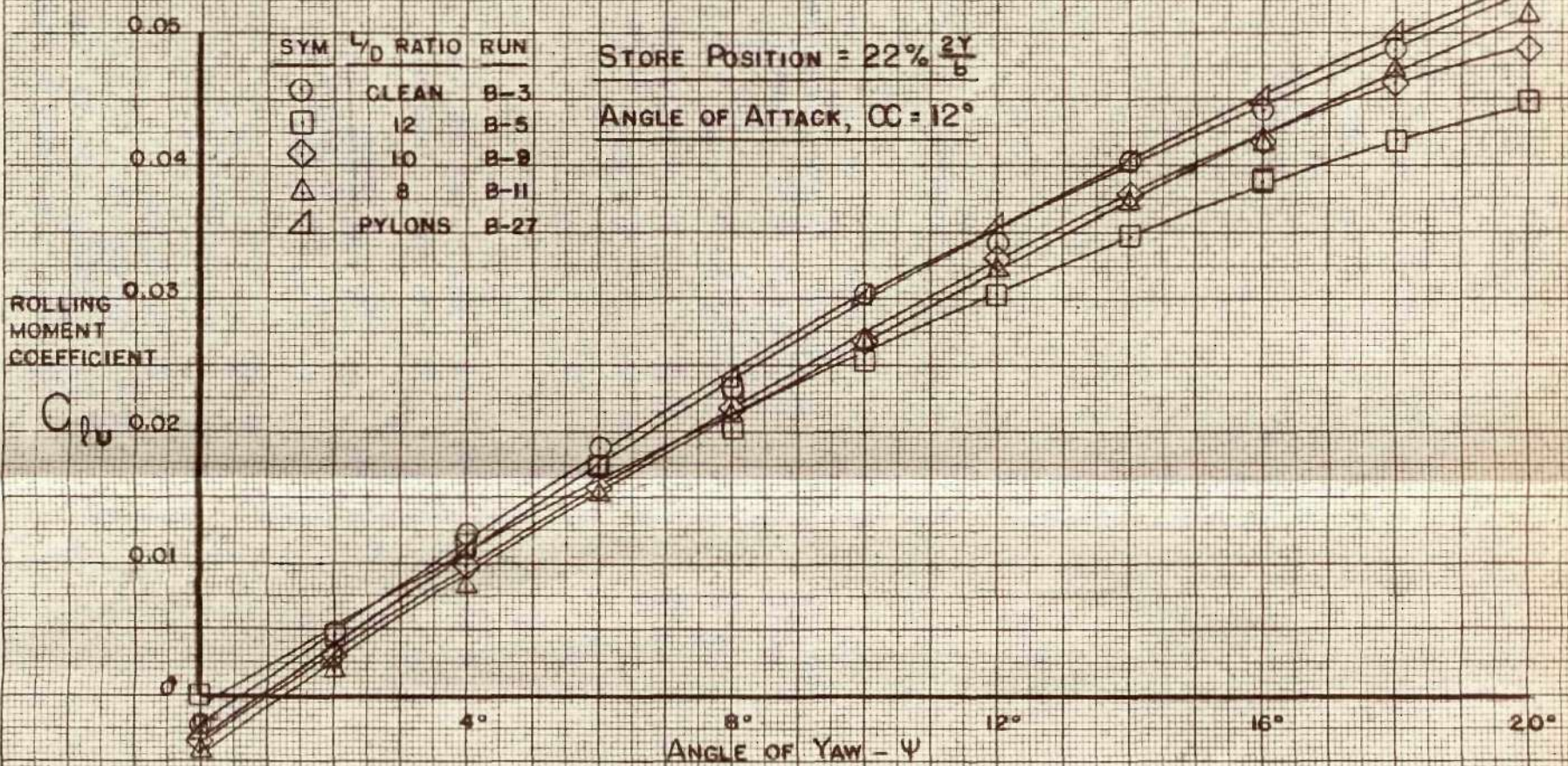
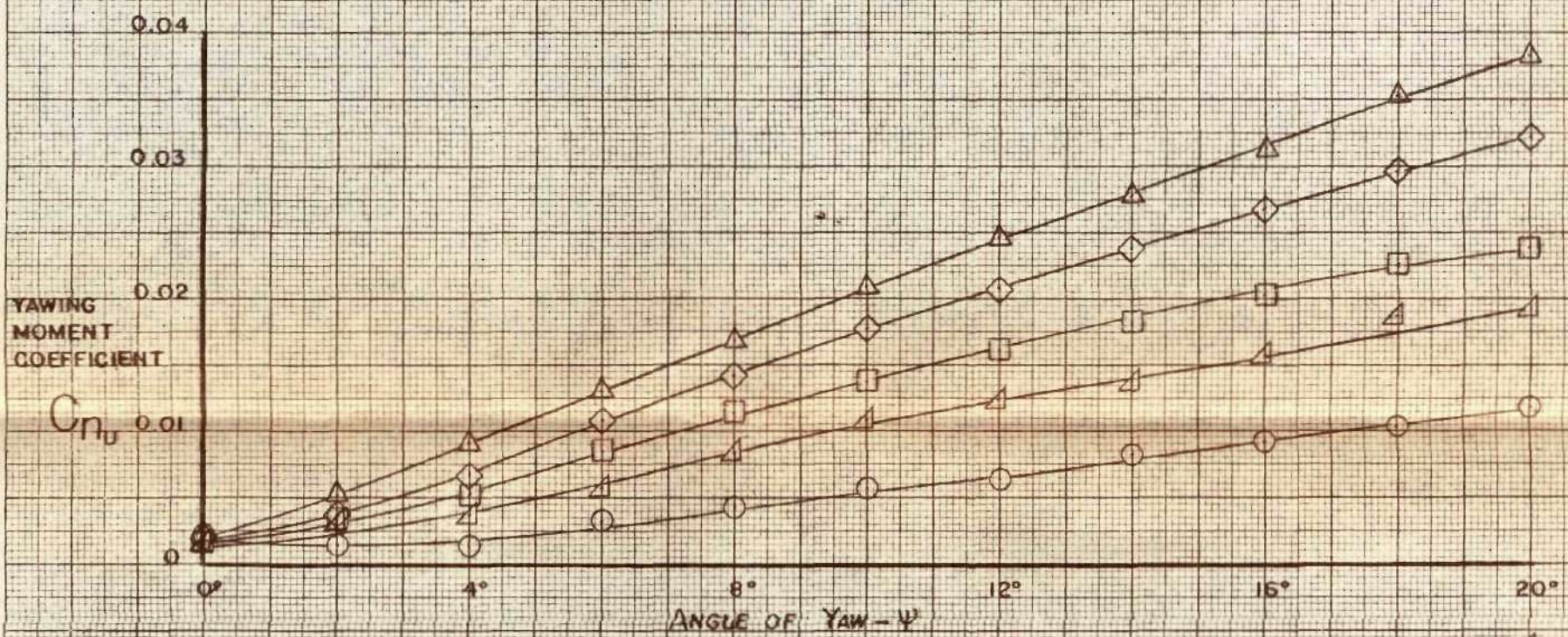
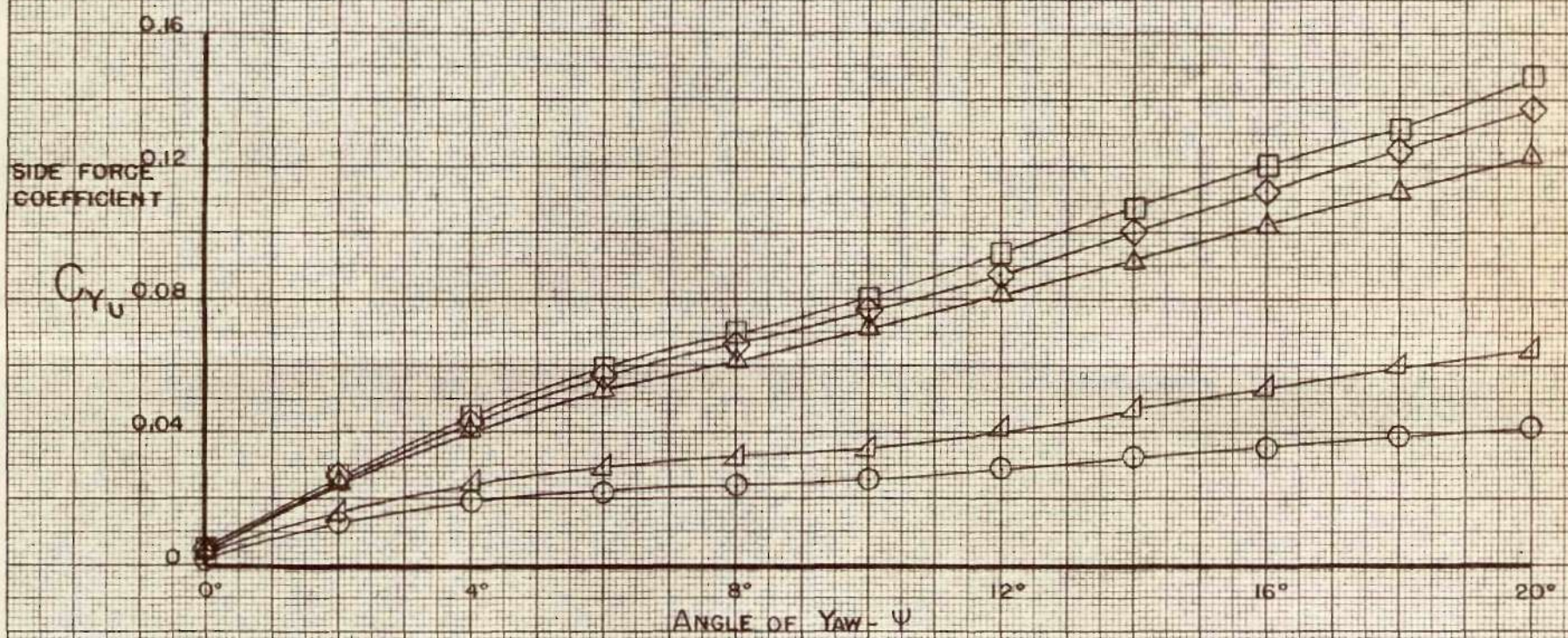
LATERAL DERIVATIVES IN YAW

FIG. 18



LATERAL DERIVATIVES IN YAW

FIG. 19

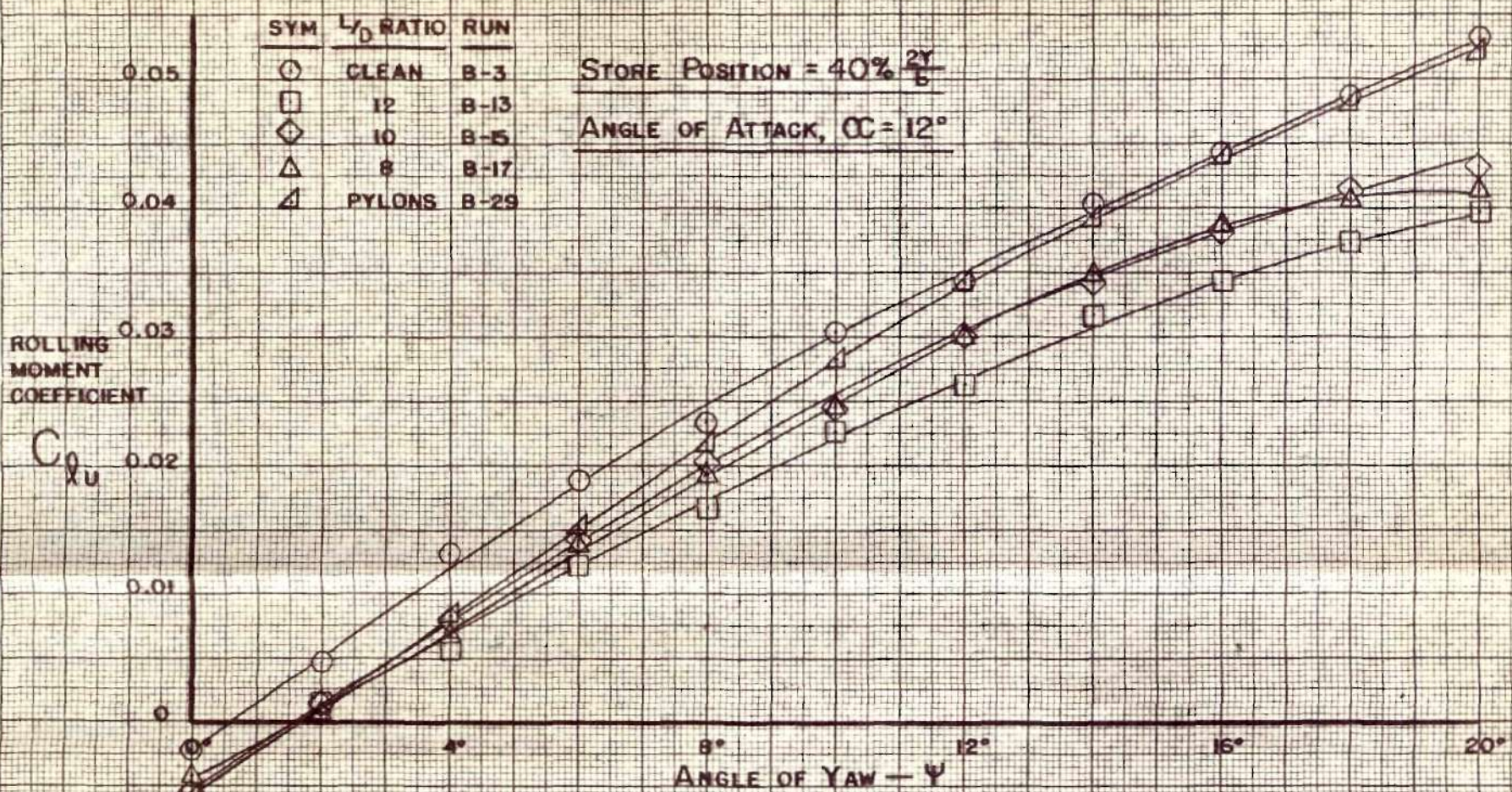
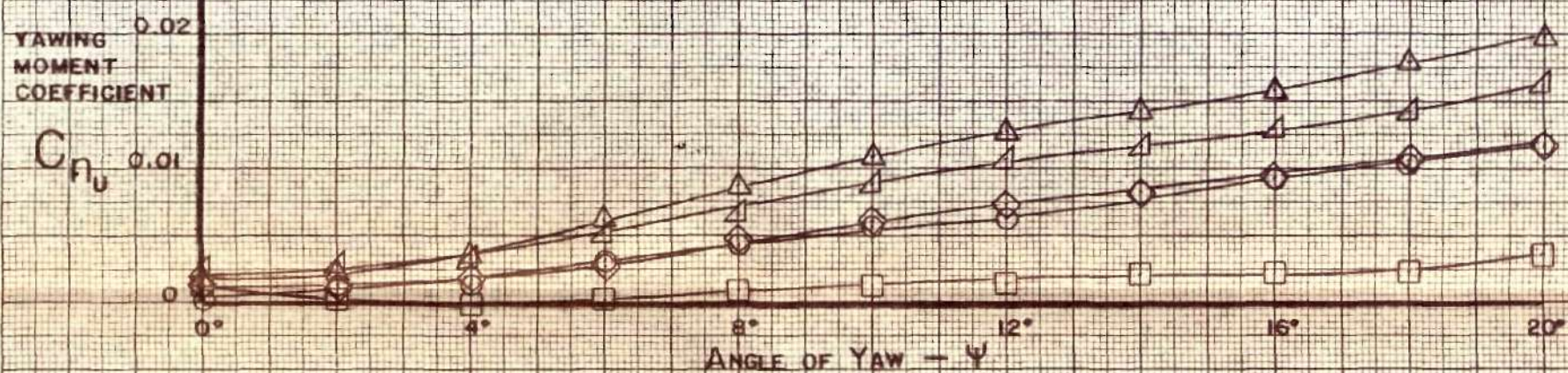
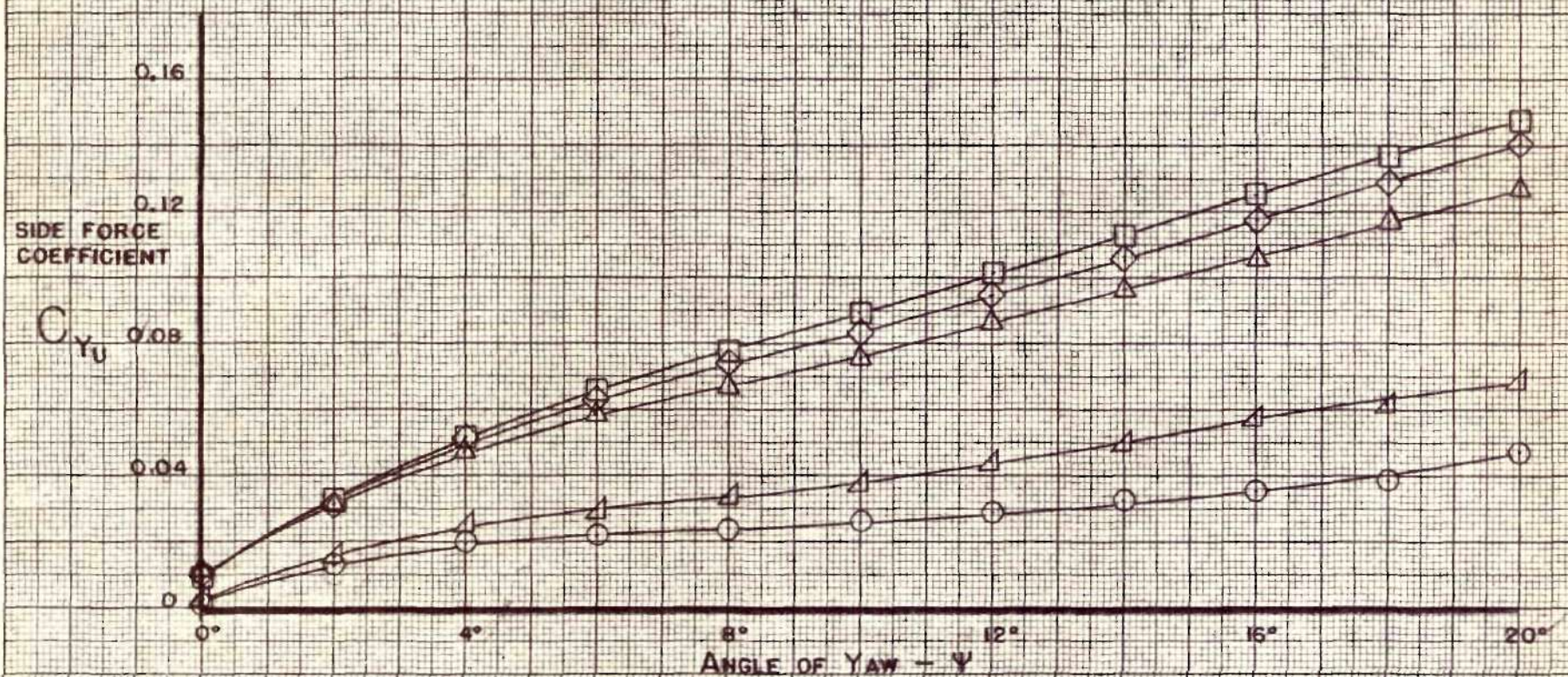


SYM	L/D RATIO	RUN
○	CLEAN	B-3
□	12	B-5
◇	10	B-8
△	8	B-11
◀	PYLONS	B-27

STORE POSITION = 22% $\frac{2Y}{b}$ ANGLE OF ATTACK, $\alpha = 12^\circ$

LATERAL DERIVATIVES IN YAW

FIG. 20



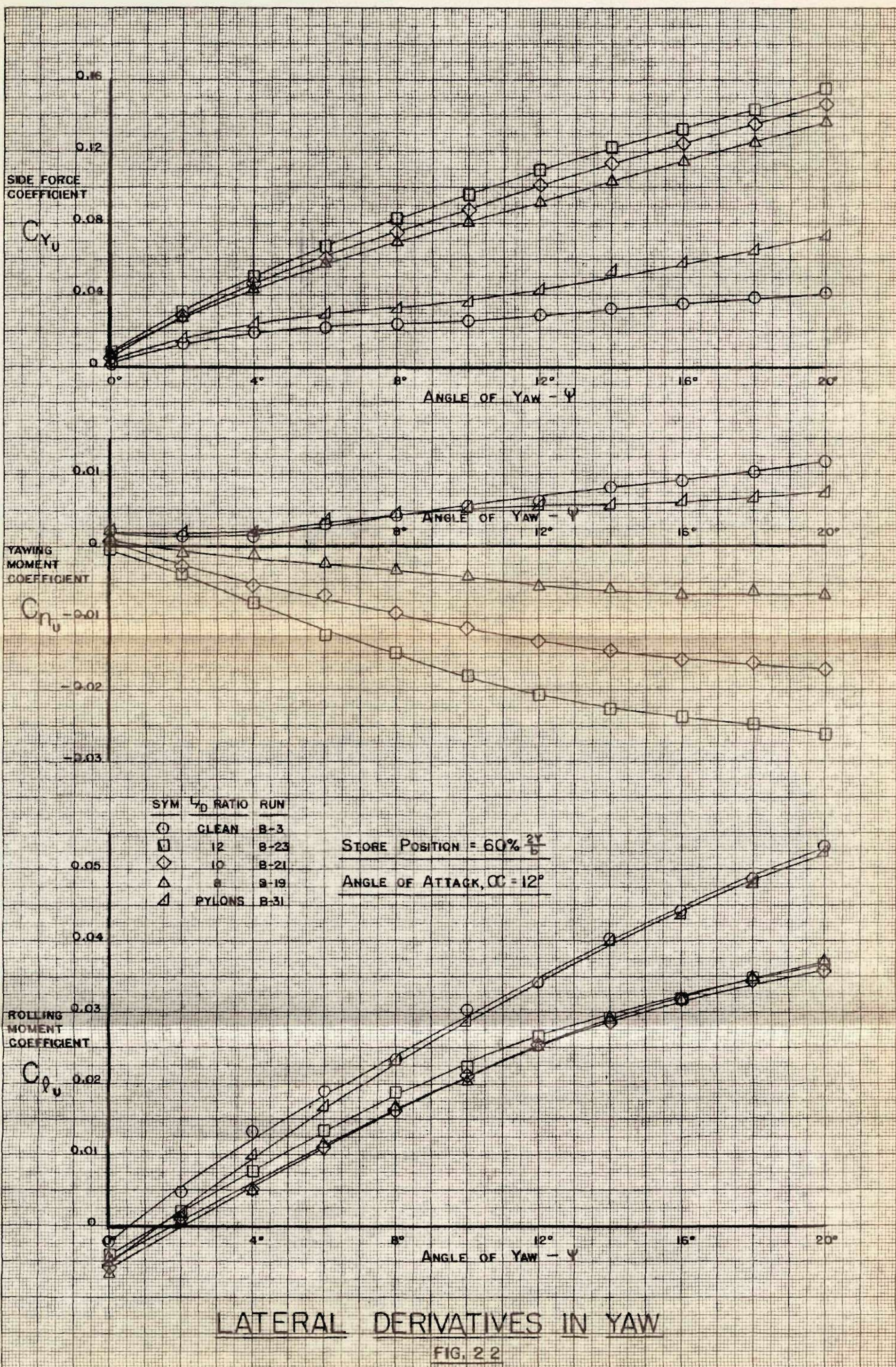
SYM	L/D RATIO	RUN
○	CLEAN	B-3
□	12	B-13
◇	10	B-15
△	8	B-17
▲	PYLONS	B-29

STORE POSITION = 40% $\frac{2Y}{L}$

ANGLE OF ATTACK, $\alpha = 12^\circ$

LATERAL DERIVATIVES IN YAW

FIG. 21



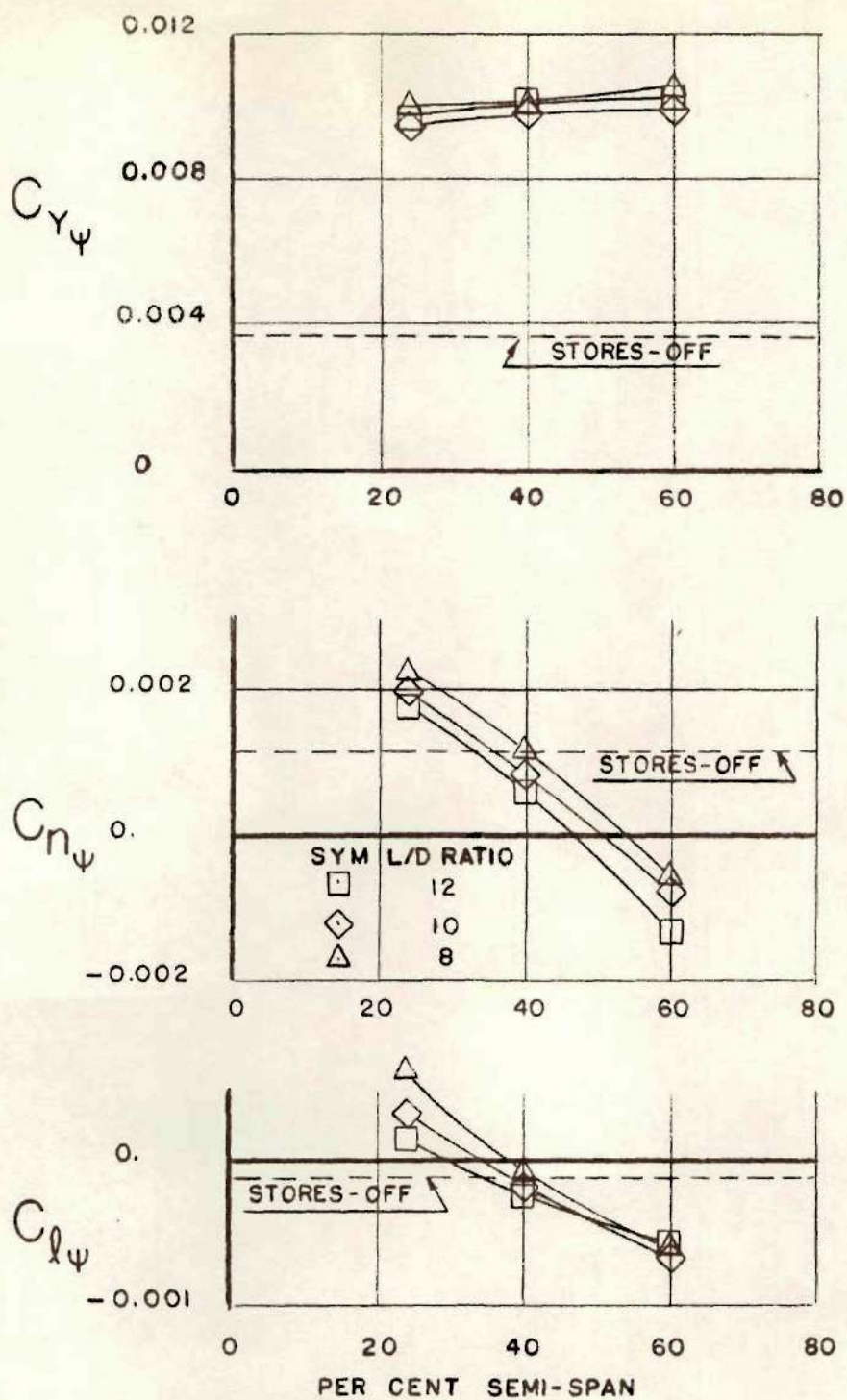


FIGURE 23
 VARIATION OF LATERAL DERIVATIVES WITH POSITION
 $\alpha = 0^\circ$

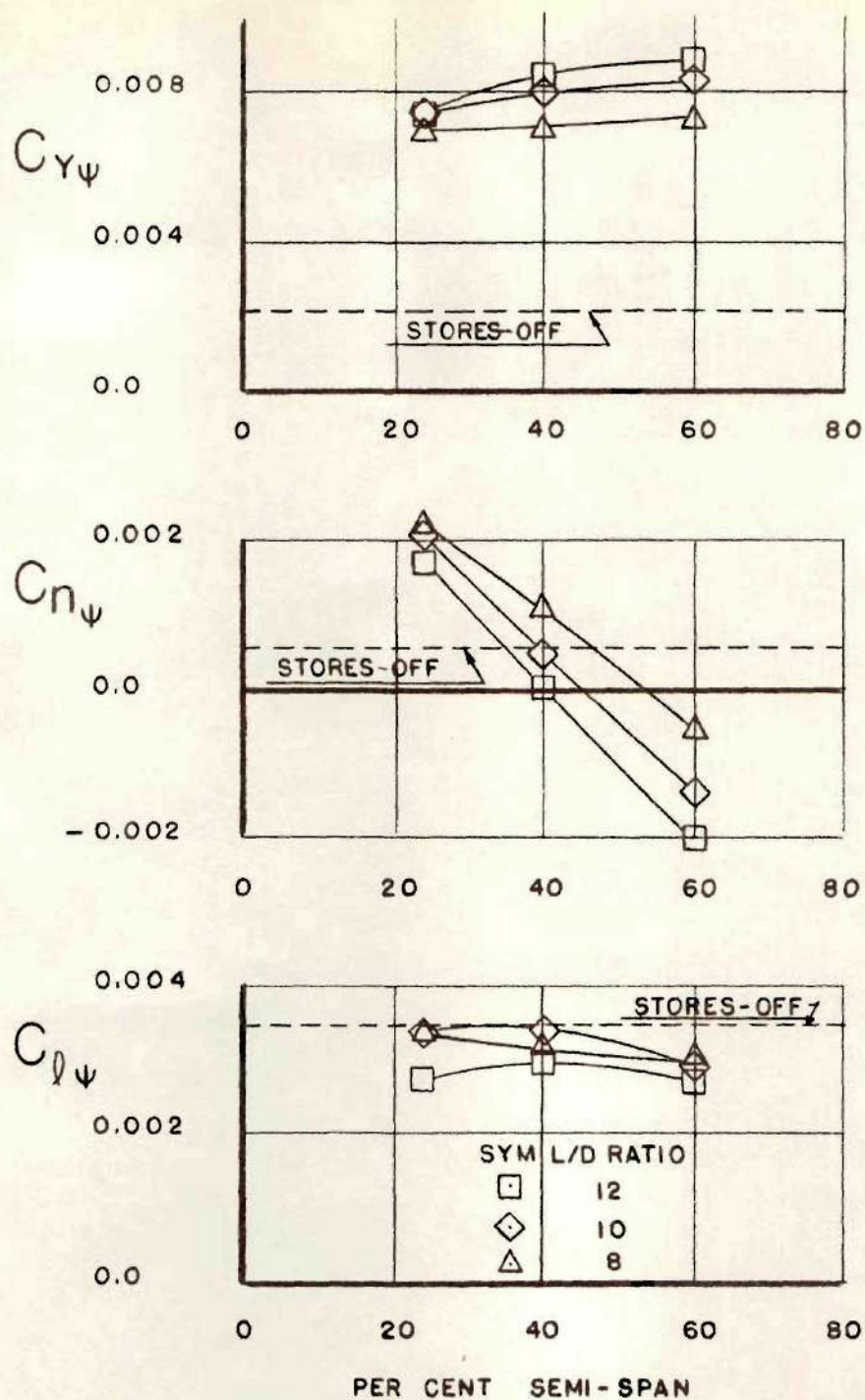


FIGURE 24
VARIATION OF LATERAL DERIVATIVES WITH POSITION
 $\alpha = 12^\circ$

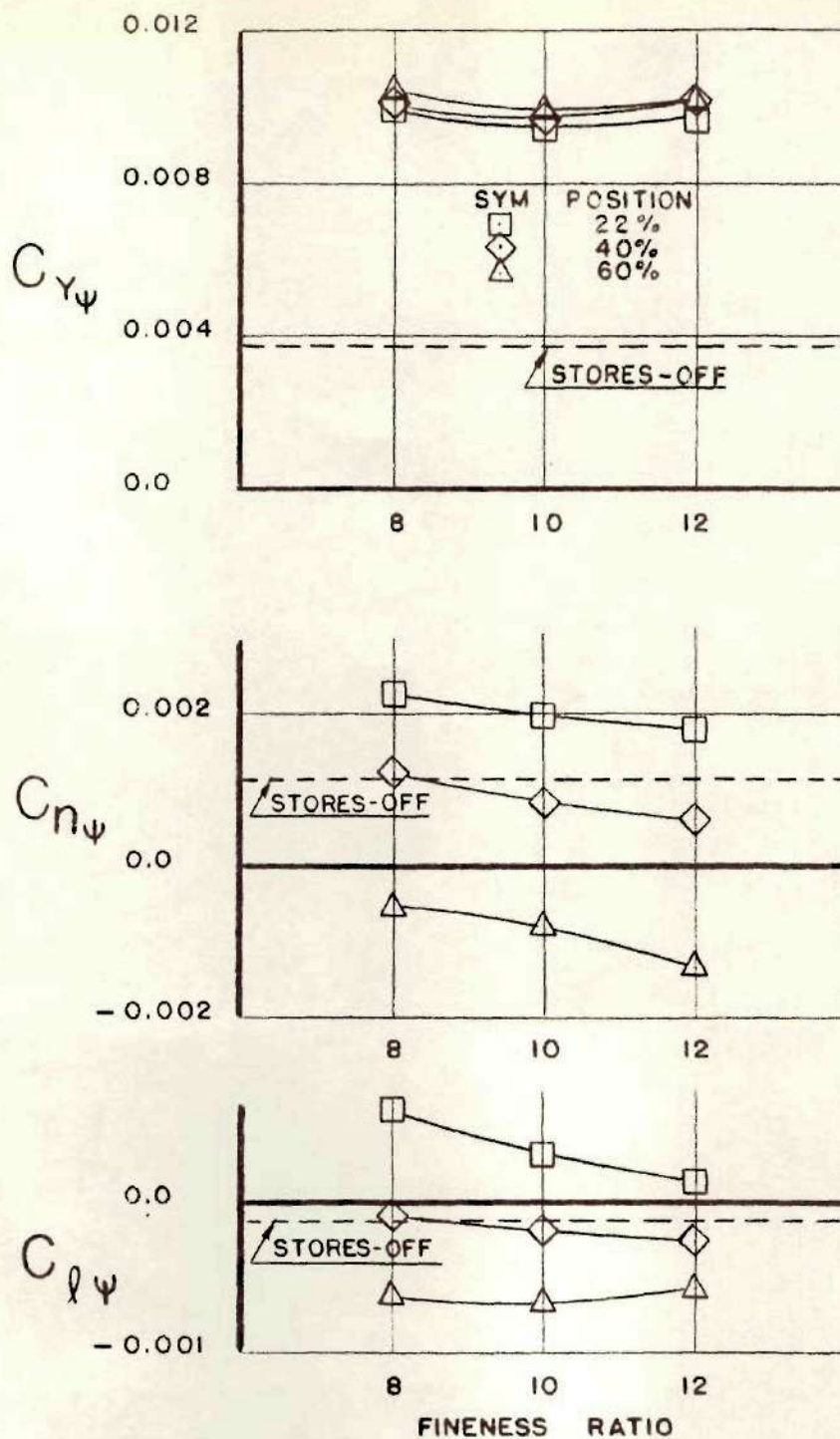


FIGURE 25

VARIATION OF LATERAL DERIVATIVES WITH FINENESS RATIO
 $\alpha = 0^\circ$

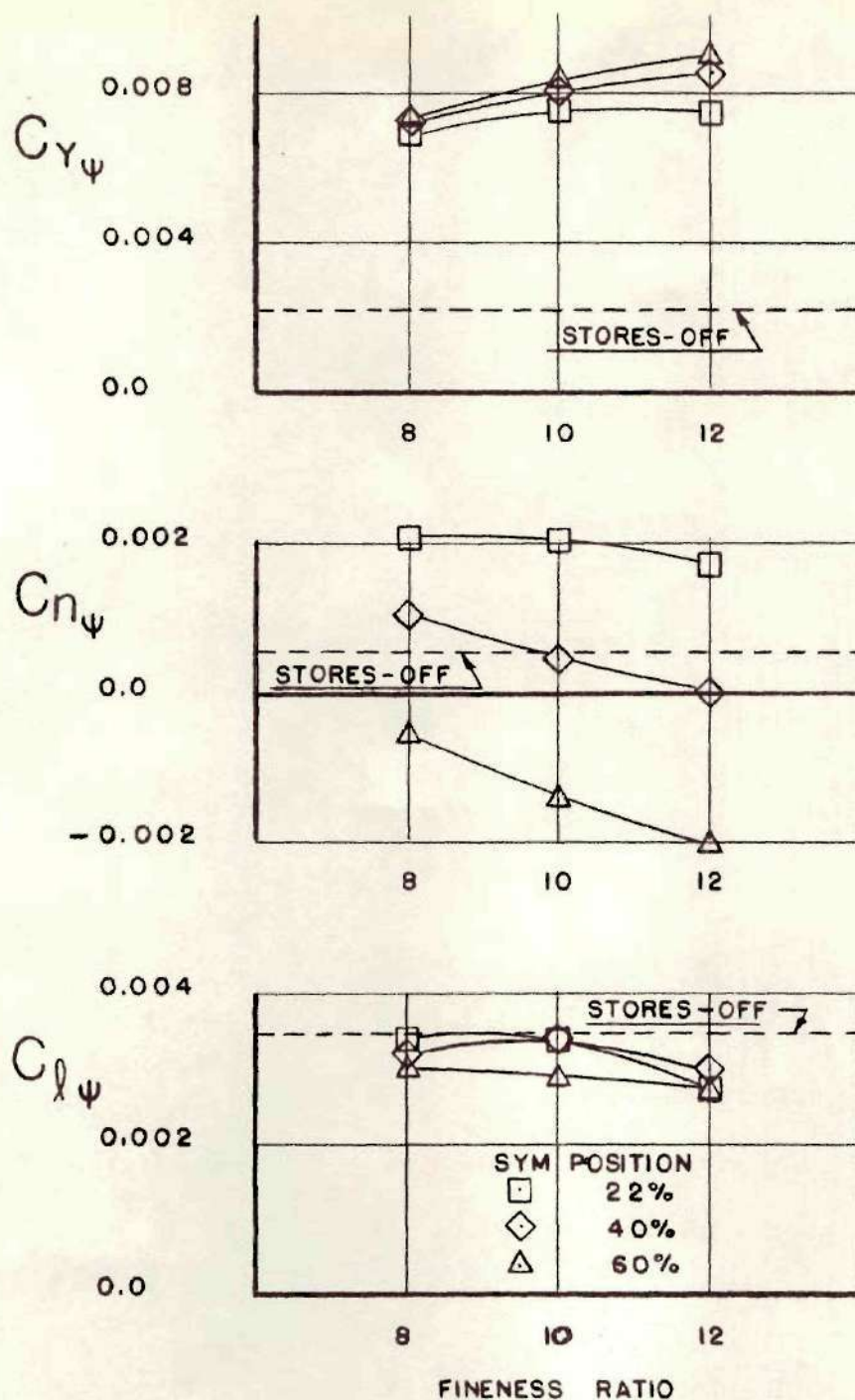


FIGURE 26

VARIATION OF LATERAL DERIVATIVES WITH FINENESS RATIO

 $\alpha = 12^\circ$

BIBLIOGRAPHY

1. Allen, Lee T., "The Effect of Large External Stores on the Low-Speed Longitudinal Aerodynamic Characteristics of a 60° Swept Delta Wing". Unpublished Masters Thesis, Georgia Institute of Technology, 1955.
2. Duncan, W. J., The Principals of the Control and Stability of Aircraft. Cambridge University Press, 1952.
3. Perkins, Courtland D. and Hage, Robert E., Airplane Performance Stability and Control. New York: John Wiley and Sons, Inc., 1949.
4. Pope, Alan Y., Wind Tunnel Testing. New York: John Wiley and Sons, Inc., 1954.
5. Powers, Sidney A., "The Effect of the Ground Plane on Low Aspect Ratio Swept Wings". Unpublished Masters Thesis, Georgia Institute of Technology, 1955.